FINAL REPORT

Building Performance Optimization while Empowering Occupants Toward Environmentally Sustainable Behavior through Continuous Monitoring and Diagnostics

ESTCP Project EW-201406

DECEMBER 2016

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ACRONYMS AND ABBREVIATIONS

AF	Asset Framework
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BACnet	Building Automation and Control Networks
BAS	Building Automation System
CMU	Carnegie Mellon University
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EUI	Energy Use Intensity
FDD	Fault Detection and Diagnostics
FEMP	Federal Energy Management Program
FM	Facility Manager
GHG	Green House Gases
HASP	Health and Safety Plan
HVAC	Heating Ventilation and Air Conditioning
ID-C	Intelligent Dashboard for Campus/City Executives
ID-F	Intelligent Dashboard for Facilities Manager
ID-O	Intelligent Dashboard for Occupants
IEQ	Indoor Environment Quality
IPMVP	International Performance Measurement and Verification Protocol
IW	Intelligent Workplace (CMU building research lab)
KPI	Key Performance Indicator
LCCA	Life Cycle Cost Analysis
MOU	Memorandum of Understanding
MSSQL	Microsoft SQL
NEAT	National Environmental Assessment Toolkit
OPC	OLE for Process Control
O&M	Operations and Maintenance

PaANG	Pennsylvania Air National Guard
PC	Personal Computer
PO	Performance Objective
POC	Point of Contact
PI	Principal Investigator
RMF	Risk Management Framework
RMSE	Root Mean Square Error
ROI	Return On Investment
RTU	Roof Top Unit
SBT	Siemens Building Technology
VAV	Variable Air Volume

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EXECUTIVE SUMMARY

Purpose of the Demonstration:

The objective of this project is to demonstrate that at least 30% of a DOD building's HVAC and plug load annual energy consumption can be saved through continuous diagnostics and controls, while empowering building stakeholders to engage in proactive energy-conservation and sustainable behaviors. The findings and performance assessments from the demonstration provide information that can help the DOD to reevaluate its building operation policies, practices and guidelines – by engaging the whole military installation community, especially building occupants, in energy conservation measures and by engaging facility managers through easy-to-use and user-friendly interfaces that support preventative measures to ensure energy conservation and occupant comfort.

Description of the Technology:

The team deployed two distinct technologies during this demonstration project. The first technology, 'ID-F,' targets building facility managers and allows real time diagnostics for BAS systems with features like benchmarking, fault detection, and diagnostic or energy anomaly detection. As an extension of traditional BAS, ID-F allows a deep performance tracking of building systems. Having a better view of their building's performance, facility managers can avoid system failures, diagnose incorrect sequences of operations, and improve occupants' comfort.

The second technology, 'ID-O,' targets building occupants, allowing them to manage and control their electrical appliances. Through features like energy feedback, automation, reminder and targeted recommendations, occupants are made aware of their appliances' energy consumption impact and are invited to change their behavior and to engage in more sustainable practices.

Results of the Demonstration:

Performance Objectives: To assess the potential for deployment of the technology at military installations in furtherance of DOD energy goals, three sets of parameters were measured in relationship to targeted expectations:

- Energy Savings – Although the success criteria was achievement of more than 30% reduction in annual energy consumption, only 10% reduction in overall energy use was realized. However, since overall energy use had been reduced for part of the test bed during the previous demonstration (EW 201336), this result understates the impact of the technology. While the target for plug-load reduction was also 30%, 24% was actually achieved.

- Greenhouse Gas Reduction – Although the success criteria was achievement of more than 30% reduction in greenhouse gas emissions, only 10% reduction was realized. (Note that the methodology used for measuring GHG is aligned with total energy measurement.)

- User Engagement Toward Sustainable Practices – All of the qualitative objectives of the demonstration were achieved: Occupant engagement was high at 85% participation, sustained positive behavior changes occurred, and satisfaction increased. Facility managers identified enhanced fault detection. And, all participants reported the system was easy to use and beneficial.

Overall Evaluation:

The demonstration validated and quantified the effectiveness of the technology in a military environment and confirmed the hypothesis that collaboration between facility managers and occupants in the control of building energy systems can reduce energy waste and increase user satisfaction. Together, the technologies behind the ID-F and ID-O dashboards provided a user-friendly, integrated platform for monitoring, analyzing, and modifying the operation of building systems and their associated energy use both in real time and over time.

The technology succeeded in identifying and exploiting multiple opportunities to adjust the scheduling of operations for building systems to the schedules of building occupants, by optimizing thermostat, air handling, and electrical base load settings during times of low and dynamic occupancy. The technology also succeeded in identifying and correcting system design and operational problems, thereby detecting equipment inefficiencies and faults and empowering predictive rather than reactive repair and maintenance strategies.

Prior to system installation, assessment of the existing BAS infrastructure of meters and data points led to hardware upgrades and equipment re-commissioning. Such improvements are inherently beneficial and should be independently cost-effective; so the process of evaluation should be considered a positive external attribute of the technology adoption process. Nevertheless, expenditure of time and money is required to prepare properly for introduction of the ID-F technology, otherwise deployment will not produce optimal results. Since the extent of required activity cannot be determined in advance, this aspect of technology introduction remains a consideration in overall evaluation.

At scale, for deployments with more than 120 occupants, the ROI for the ID-O technology is projected at 20%, with payback expected in less than 5 years. Because the dashboards are intuitive, training is straightforward, customer support is minimal, and user acceptance is high.

In conclusion, the technology did not meet its energy reduction targets but succeeded in meeting its user satisfaction goals. The savings in energy use and associated cost were substantial, despite being less than anticipated. Overall, the technology performed as designed and accomplished all of its complex missions, although with less impact than hoped for.

1.0   INTRODUCTION

Carnegie Mellon University (CMU) - in collaboration with OSIsoft, Siemens Building Technology (SBT), Energy Efficiency LLC (EEme) and Evolve Foundation, Inc. - demonstrated application of an innovative integrated software platform for the project entitled "Building Performance Optimization while Empowering Occupants toward Environmentally Sustainable Behavior through Continuous Monitoring and Diagnostics." The system was demonstrated at buildings of the 171st Air Refueling Wing of the Pennsylvania Air National Guard (PaANG) located at the Pittsburgh International Airport in Coraopolis, Pennsylvania, using funding provided by the U.S. DOD Environmental Security Technology Certification Program (ESTCP). Within 20 months, the project team demonstrated and validated the base-wide building energy efficiency improvement capability of the integrated systems as well as the beneficial impacts of the systems on increased awareness of energy conservation opportunities and active engagement in workplace energy efficiency enhancement by DOD personnel.

To maintain and operate its facilities, the DOD is spending almost $4 billion yearly on energy related costs. As required by legislation (EISA 2007), the DOD is investigating available solutions to reduce the energy consumption of its building inventory. Several studies have shown that the controls of most building systems drift over time due to lack of understanding, monitoring, and diagnostics. The resulting inefficiencies drastically reduce the performance of systems while decreasing user satisfaction because of increased mechanical noise, increases in building pollutants, inadequate indoor temperature set points, and other factors. For example, more than 50% of air economizer systems fail to perform within design specifications within their first three years of operation, leading to over-consumption of energy by more than 40% in certain climate zones [1-2].

To maintain optimal performance over the building lifetime, building systems need to be monitored continually; their performance needs to be trended; drifts or anomalies need to be detected, analyzed and reported. Because various hardware manufacturers use proprietary communication protocols, robust infrastructure-wide systems are essential for cross-platform integration. Energy savings of up to 40% are achievable in commercial buildings by continuously monitoring, analyzing and reporting building performances [3-5].

Building occupant activities also impact the overall performance of buildings. Unfortunately, a lack of information or feedback for users can lead to unintentionally detrimental behavior. To create awareness for building occupants, technology displaying building energy performance metrics and recommendations (such as a dashboard system) can engage the occupants toward pro-environmental behavior and energy conservation practices. A synergy of manual and automated control can be achieved by giving occupants control of their environments, thereby improving their comfort, satisfaction and productivity. For example, preliminary studies have shown that more than 30% of plug load energy can be saved by raising awareness of plug load management practices [6].

This document describes the work performed and the results achieved during the demonstration of the systems at the PaANG site. In addition to validating and quantifying the effectiveness of the technology, the demonstration allowed the project team to determine the system installation costs, assessed the system's risk management framework and cyber-security acceptance, and provided a viable transfer plan to other DOD sites.

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1.1   BACKGROUND

The Pacific Northwest National Laboratory of the DOE (PNNL) reports that the DOD accounts "for roughly 60% of energy use and floor space" for federal buildings [Sec. 2.1.2] but has not been on track to meet the goal of 30% energy intensity reduction by FY 2015 [Sec. 2.2] [7]. PNNL also reports that approximately 53% of the 318,090 total DOD buildings are houses, office buildings and schools [8]. Buildings of these types are usually in active use for several hours per day with dynamic occupancy. However, a typical state-of-the-art Building Automation System (BAS) used by the DOD supports only static HVAC and lighting schedules; and existing DOD energy policies often limit control of the environment within these spaces to building operators and facility managers. In most cases, buildings are managed to provide regulated environmental conditions designed to support high comfort levels for maximum occupancy during periods of time that are longer than necessary, e.g., 6am-11pm daily, in order to avoid occupant complaints. This management policy leads to substantial energy waste without necessarily delivering occupant satisfaction. In fact, based on surveys conducted at DOD sites and studies in civilian settings, occupant complaints are frequent at those buildings that adopt such policies; and, ironically, typical complaints are about buildings being over-cooled in summer and over-heated in winter.

At PaANG, where typical work schedules for National Guard personnel are followed, we found that about 60% of the employees who are assigned to occupy base facilities do so on a limited basis. Furthermore, because the schedules of these "part-time" individuals are subject to change, the BAS is set to air condition the space as if they were "full time" employees. The energy waste due to such persistent, excessive overscheduling, over-ventilation, and over-lighting is significant.

Lack of occupant participation in the control of the building is hypothesized to be the main reason for both energy waste and comfort complaints.

To address these problems, CMU and OSIsoft have developed an innovative, low-cost, integrated software platform that allows interactive communications and actions among occupants, facility managers, and building control systems for both individual building and base-wide applications. CMU has developed "Intelligent Dashboards" at scales for building occupants (ID-O), facility managers (ID-F), and city/campus (ID-C) to provide real-time energy and Indoor Environmental Quality (IEQ) analytics and communications based on sensor and controller information collected and managed by OSIsoft's PI Systems database.

Savings in direct building energy use (and associated energy cost) of at least 30%, including savings of 40% in plug load energy use, is expected from the adoption of the integrated system for all types of DOD buildings used for operations at a military base. Furthermore, use of the systems is expected to enhance the comfort of building occupants and the efficiency of building operators, leading to a more productive workplace with fewer complaints.

1.2   OBJECTIVE OF THE DEMONSTRATION

The objective of this project is to demonstrate that at least 30% of a DOD building's HVAC and plug load annual energy consumption can be saved through continuous diagnostics and controls, while empowering building stakeholders to engage in proactive energy-conservation and sustainable behaviors.

The team deployed two distinct technologies during this demonstration project.

The first technology, 'ID-F,' targets building facility managers and allows real time diagnostics for BAS systems with features like benchmarking, fault detection, and diagnostic or energy anomaly detection. As an extension of traditional BAS, ID-F allows a deep performance tracking of building systems. Having a better view of their building's performance, facility managers can avoid system failures, diagnose incorrect sequences of operations, and improve occupants' comfort.

The second technology, 'ID-O,' targets building occupants, allowing them to manage and control their electrical appliances. Through features like energy feedback, automation, reminder and targeted recommendations, occupants are made aware of their appliances' energy consumption impact and are invited to change their behavior and to engage in more sustainable practices.

The findings and performance assessments from the demonstration provide information that can help the DOD to reevaluate its building operation policies, practices and guidelines – by engaging the whole military installation community, especially building occupants, in energy conservation measures and by engaging facility managers through easy-to-use and user-friendly interfaces that support preventative measures to ensure energy conservation and occupant comfort.

The project team conducted training sessions for the facility managers and building occupants during the introduction of the ID-O and ID-F technologies. Usability feedback surveys were used to obtain input for updating interfaces. In addition to training sessions, the team provided manuals to building occupants who participated in the ID-O demonstration. All of these activities are intended to increase awareness and acceptance of the technology within the demonstration site and for the DOD in general.

1.3   REGULATORY DRIVERS

The energy saving activities of this demonstration are aligned with Executive Orders, legislative mandates, federal policy, DOD policy, and the Air Force Energy Strategic Plan.

Executive Order:

EO 13693 of March 25, 2015 (superseding EO13423 of January 24, 2007) Planning for Federal Sustainability in the Next Decade:

In compliance with this executive order, Federal agencies must conduct their environmental, transportation, and energy-related activities in an environmentally, economically, and fiscally sound manner. "To improve environmental performance and Federal sustainability, priority should first be placed on energy use." The technology used in this demonstration specifically addresses two subsections of Section 3 of EO 13693:

- Sec. 3. (a): "promote building energy conservation, efficiency, and management by: (i) reducing agency building energy intensity…, by implementing efficiency measures based on and using practices such as:…
    - (E) Implementing space utilization and optimization practices and policies; and
    - (F) Identifying opportunities to transition test-bed technologies to achieve the goals of this section."

Legislative Mandates:

Energy Policy Act of 2005, Energy Independence and Security Act of 2007

These laws serve to move the United States toward greater energy independence and security, increased efficiency of products and buildings, and improved energy performance by the Federal Government. The technology used in this demonstration specifically addresses the mandate of both Title III: Energy Savings Though Improved Standards for Appliance and Lighting and Title IV: Energy Savings in Buildings and Industry. The core objective of this project is demonstration of the integrated systems' abilities to achieve energy savings by following the guidelines and regulations stipulated in the mandates and in the industry standards.

Federal Policy:

Federal Leadership in High Performance and Sustainable Buildings MOU 2006

This MOU between federal agencies commits them to leadership in the design, construction, and operation of buildings through implementation of common strategies that incorporate and adopt, as appropriate and practical, certain Guiding Principles which include those designed to Optimize Energy Performance (Guiding Principles Section II) and Enhance Indoor Environmental Quality (Guiding principle Section IV).

DOD Policy:

Strategic Sustainability Performance Plan, Energy Security MOU with DOE

This plan directs US military departments to execute their missions in a sustainable manner that attends to energy, environmental, safety, and occupational health considerations. Incorporating sustainability into DOD planning and decision-making ensures that current and emerging mission needs are addressed, along with anticipation of future challenges. The technology used in this demonstration specifically addresses plan…

- Goal 7: "Sustainability Practices Become the Norm,"

- Sub-Goal 7.2: "15% of Existing Buildings Conform to the Guiding Principles on High Performance and Sustainable Buildings By FY 2015, and Thereafter Through FY 2020."

Service Policy:

Air Force Energy Strategic Plan (March 2013)

This plan builds on a core set of goals, objectives, and metrics designed to provide the platform for continuous improvement in Air Force energy management techniques. The technology used in this demonstration specifically addresses the following goals:

- Priority 1 – Improve Resiliency: "Improvement of operational efficiency and energy efficiency for existing systems."

- Priority 2 – Reduce Demand: "In order to Reduce Demand, the Air Force must improve energy performance of operational platforms and enhance the energy efficiency of fixed infrastructure."

- Priority 4 – Foster an Energy Aware Culture: "Cultivate an energy-aware force using communications targeted to the unique interests of segments of Airmen by leveraging all available tools, including social media, to increase energy awareness while personalizing each Airman's role in energy efficiency and energy security."

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

2.1.1 Description:

The Intelligent Data and Dashboard for Facility Managers (ID-F) provides real-time access to the full range of energy metering and BAS system data available on the DOD campus, drawing from a unified database created on a PI Server. The OSIsoft PI data infrastructure is a vendor independent software platform which can integrate, extend and improve existing Building Automation Systems (BAS) capabilities, a Siemens Apogee system in the case of PaANG. In addition, existing building electricity meters and newly installed electrical meters provided real time interval data in the database. OSIsoft's PI System supports integration and interoperability since it is compatible with more than 450 different communications protocols, such as BACnet, Modbus, OPC and others.
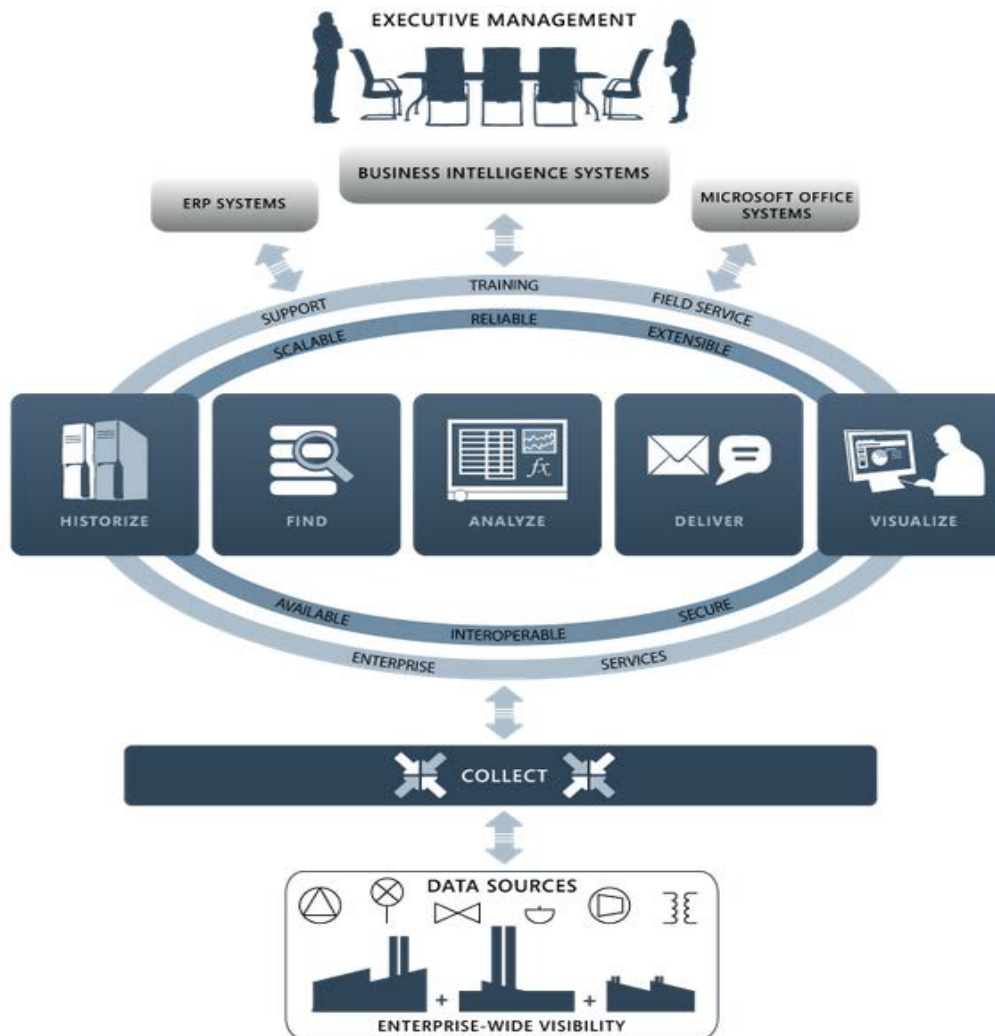
Figure 1. PI OSIsoft Framework

The shared data infrastructure allowed us to retrieve data from meters and sub-meters as well as sensors, actuators, and equipment variables tracked by the BAS of the 14 buildings on the PaANG campus. The database supports long term archiving, iterative analysis and customized displays for PaANG decision makers, with real-time visualization and analytical interfaces that integrate, monitor and evaluate energy and system performance variables that were developed by the research team. These interfaces were built using a range of client tools to perform analytics and calculations, to generate operator alerts as required, and to visualize the data and the analytical results (PI Coresight and Processbook, Figure 1). Described further in the next section, this capability delivers significant, immediate value because it allows Facility Managers and decision makers to monitor and compare their system data comprehensively.

In a parallel effort, this ESTCP project studied the impact of a plug load monitoring and control dashboard for the occupants in Building 205. This Intelligent Data and Dashboard for Occupants (ID-O), was installed at 8 workstations to support monitoring and control of desktop technology and electrical appliances. Multiple Plugwise™ smart plugs were installed at each workstation to continuously monitor the electricity consumption of key technologies and to support on-line or automated on-off controls for those technologies. (A smart plug is a device inserted between an electrical outlet and the cord for an electrical appliance that is able to monitor, report, and control electricity use: See Appendix 4 for details) This Dashboard provides real time communication, expert feedback, and on-line and automated control for the occupants, further discussed in subsequent sections. Six months of baseline energy use data were recorded before the Intelligent Dashboard was installed.

Within 20 months, the project team demonstrated and validated the base-wide building energy efficiency improvement capability of the integrated systems as well as the beneficial impacts of the systems on increased awareness of energy conservation opportunities and active engagement in workplace energy efficiency enhancement by the DOD personnel.

2.1.2   ID-F Intelligent Dashboards for Facility Managers

Creation of the Base Building Portfolios

The first step in this research project was the collection and aggregation of data from multiple BAS, online records, and meter sources into a common database. The PI Asset Framework (PI AF) was used to create an object oriented hierarchical model (see Figure 2) in order to capture both facilities' real-time data and relational data (maintenance diagrams and manuals, repair part info, maintenance histories), thereby providing a comprehensive asset management capability. For military application, this technology enables the analysis of various buildings within a base and allows the creation of a building portfolio for all DOD facilities.
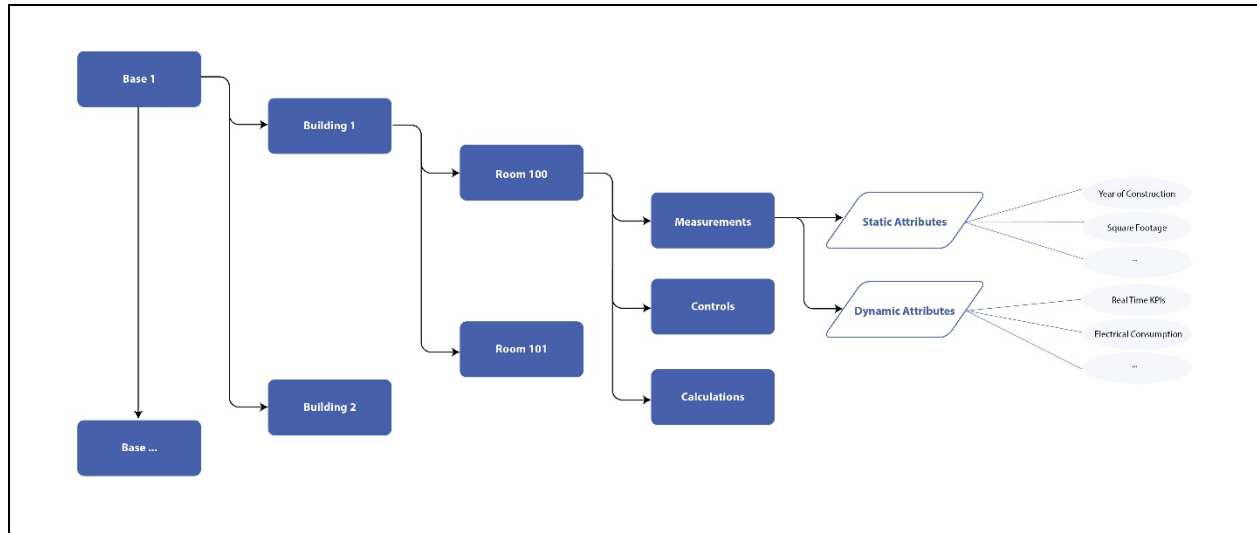
Figure 2. Example of a PI AF Object Oriented Hierarchical Model

Assembled in the PI system, the aggregated data were accessible at anytime by the PaANG facilities team. Trends of historical information can be quickly displayed using PI Coresight at multiple time intervals (see Figure 3) as well as provide spatial information (see Figure 4).

Figure 3. Web-based PI Coresight Interface (time interval)

Enabling Continuous Monitoring and Diagnostics

With the initiation of an integrated database accessible to decision makers, several building energy performance tools were introduced:

- **Benchmarking**: EUI metrics (kwh/ft2) were created for comparison with buildings that have similar specification (building type, size, occupancy, year of construction, etc.).

- **Spatial Information Display**: Installation and building-specific energy and BAS data displays were created for easy access to real-time and trended data sets (see Figure 4).

- **Energy Anomaly Detection** using simulation of Key Performance Indicators (KPIs): Boundaries of acceptable energy consumption were defined around the simulation of optimal performance. Using the PI Notification tool, alarm notifications (by email, and on-screen flags) were triggered and delivered to specified users whenever measured data fell outside the KPI boundaries.

- **Quality Control**, **Fault Detection and Diagnostics**: CMU/OSIsoft developed an automated data quality control that assessed field values for proper range and performed energy balance checks at the component, equipment, and system levels. Alarms were triggered each time that field values were detected outside their proper defined ranges.
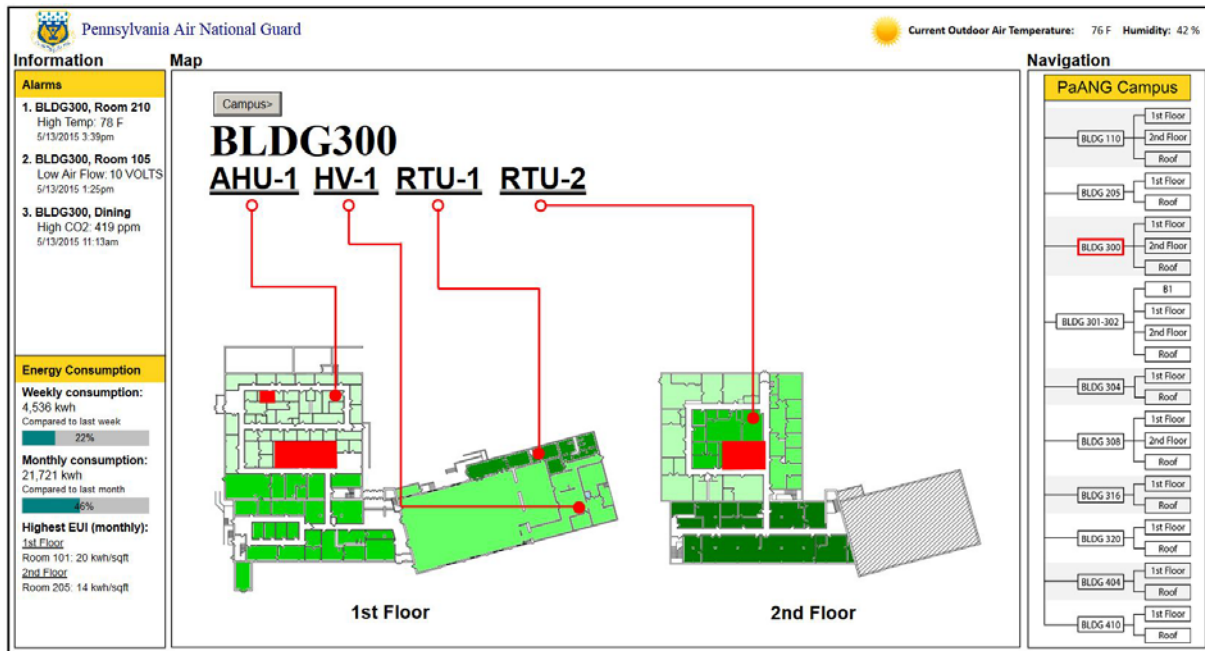
Figure 4. A Floor Plan with Zone Temperature in PI Coresight

2.1.3   ID-O Intelligent Dashboards for Building Occupants

Plug load energy demands constitute up to 30% of workplace energy consumption today [1]. By enabling occupants to monitor and control their desktop technologies and appliances, significant energy savings can be achieved. CMU, with both public and private partners, had undertaken extensive efforts to refine the ID-O dashboard for plug load management and was ready to demonstrate this dashboard in a DOD facility.

The interface was deployed for 8 building occupants in Building 205 to provide real-time information on plug load energy consumption, expert recommendations, and online control. As illustrated in Figure 5, the main features of the Intelligent Dashboard are:

- **Communication:** The self-monitoring interface displays real-time and historic data for each monitored device in the office. The dashboard provides different chart options: daily, weekly and monthly; bar charts and continuous plots; precise energy demands; and comparative use among workgroup peers.

- **Expert Consulting:** Unlike most dashboards that provide only generic advice, the intelligent dashboard recommendations for action are generated on-the-fly, based on specific energy use patterns. The advice can be short-term (e.g. turn off the equipment at night and during weekends) or long-term (e.g., replace the excessive energy-using equipment with an Energy Star™ device) based on actual use patterns and energy use databases.

- **Control:** Most dashboards do not allow occupants to personally control equipment. The dashboard has several control strategies to enable occupants to reduce unnecessary energy uses: clicking a digital on-off button, setting up group controls, and adding calendars and schedules (see Figure 6).
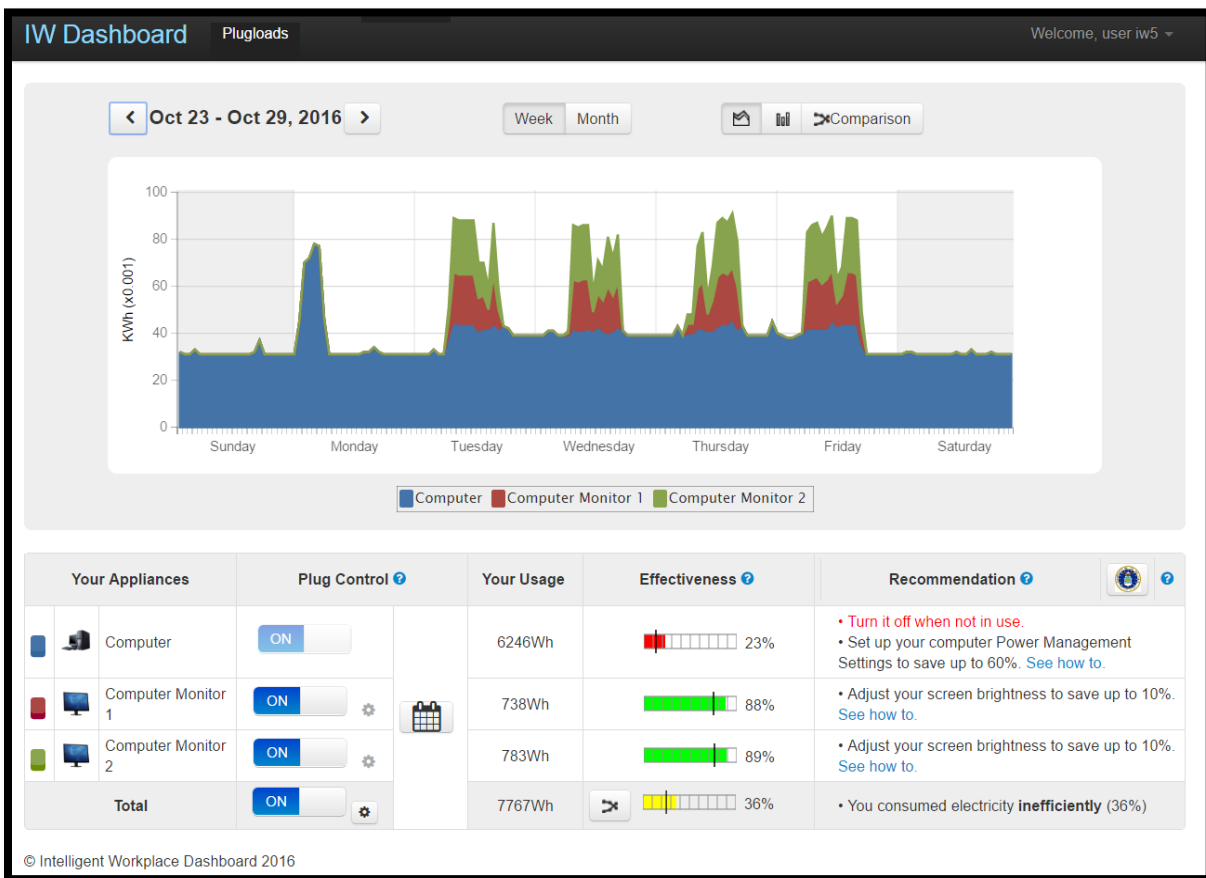
Figure 5. The Plug-load Dashboard Home Screen

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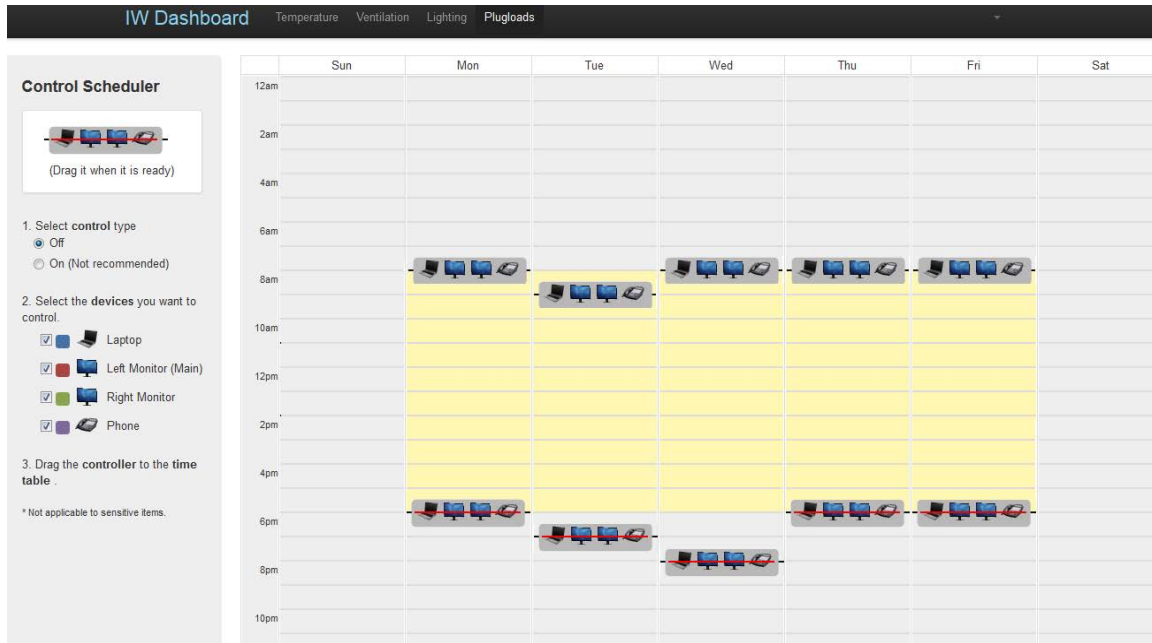
Figure 6. Calendar Function to Control (ON-OFF) Electrical Appliances

2.1.4 Chronological Summary:

A chronological summary of the ID-F and ID-O technology development is presented below in Table 1. Although ID-F and ID-O have been developed in tandem and designed to work together, they interface with separate users, facility managers and building occupants; and, therefore, constitute distinct technologies that are integrated within the software platform. "Maturity Level" assessment of the technologies' state of development is assessed on a scale of 1 (conceptual design) to 9 (commercial acceptance in the marketplace). ID-O is currently at Level 8 (complete system qualified through test and demonstration) while ID-F is currently at Level 6 (prototype demonstration in a relevant environment).

Table 1. Chronological Summary of the Technologies Development

Features	Period	Funding Agency	Maturity Level
ID-O			
Cloud-Base ID-O System	2011-2013	DOE	5
ID-O Deployment at PNC BANK	2013-2014	DOE-CMU	6
ID-O System architecture redesigned matching DOD requirements	2015-2016	DOD	7
ID-O Refinement for Local deployment	2016	DOD	7-8
ID-F			
Drivers for BAS system	2012-2014	CMU	5
Front End Interface for Facility Managers	2013-2015	DOE-DOD	6
Automated Discovery and Mapping of BAS Points	2013-2015	DOE	6

2.1.5   Future Potential for the DOD:

The benefits and applications of the integrated building data analytics platform are categorized below for various DOD stakeholders:

1. For *Policy/Decision Makers*, the information supports data-driven policy-making and assessments, and the planning of prioritized energy conservation measures.

2. For *Facility Managers* and *Building Operators*, the data platform supports proactive operations and maintenance to reduce energy consumption and provide superior IEQ, thereby optimizing building portfolio performance.

3. For *Building Occupants*, the energy and IEQ information creates greater awareness and promotes engagement in energy and resource conservation.

4. The *Public* gains greater access to the environmental footprint of the military installation with verified metrics and key performance indicators.

The ID-F PI-based platform can be installed, as designed, in DOD facilities throughout the world and provide potential dynamic benefits. In addition to collecting and analyzing data, the data platform stores the time-series data indefinitely. Since the historical data is not lost but stored in the facility's internal system, DOD Facility Managers, Building Operators, and other DOD researchers and contractors can use the historical data to further optimize existing building operations. Additionally, the data format and system was developed so that future DOD Facility Managers, Building Owners, and researchers could develop applications, algorithms, and customized information presentations to help them support further energy conservation while increasing occupant comfort, satisfaction and performance in their facilities.

2.2   TECHNOLOGY DEVELOPMENT

Four independent systems were introduced in this project: [1] the OSIsoft PI system, [2] the ID-F dashboard, [3] the Plugwise monitoring and control hardware, and [4] the ID-O dashboard. Each system has measurable track records from previous projects/demonstrations.

OSIsoft and its PI System specializes in real-time data acquisition for the process engineering industries, bringing more than 30 years of experience in capturing, processing, analyzing, and storing data relating to manufacturing processes. Using data from such sources as automated control systems, the PI System applications monitor and analyze production processes to find ways to streamline operations. The PI System is distinguished by its ability to gather, store, and retrieve an almost unlimited number of points from a large range of operating systems, as well as to provide a rich set of analysis and display tools for the user.

The project team at the Center for Building Performance and Diagnostics (CBPD) at CMU was one of the early adopters of the PI System for building utility and BAS data capture and analytics. In collaboration with Siemens on a DOE project [EE0004261], the CMU team and OSIsoft engineers developed an integrated monitoring system for the Robert L. Preger Intelligent Workplace, a 7,000 square foot living laboratory of office environmentsand innovations located on the campus of Carnegie Mellon University. To support integrated ventilation (mechanical and natural), heating, cooling, lighting, and daylighting control strategies, the PI System is used as the real-time data platform in the facility (see Figure 7).

Other research efforts have experimented with the links between PI and BACnet to provide occupants with immediate sensor information and even access to controls. Using the capability of the BACnet protocol, occupants can control the various systems (blinds, louvers, lighting, temperature set points) in their own workspaces. With further development, messages and alerts (via email or phone text messages) will notify building occupants of real time IEQ data and advise them on better sustainability practices for their workspace. Facilities managers will also be informed of the status of building systems using the notification system that is currently under development.
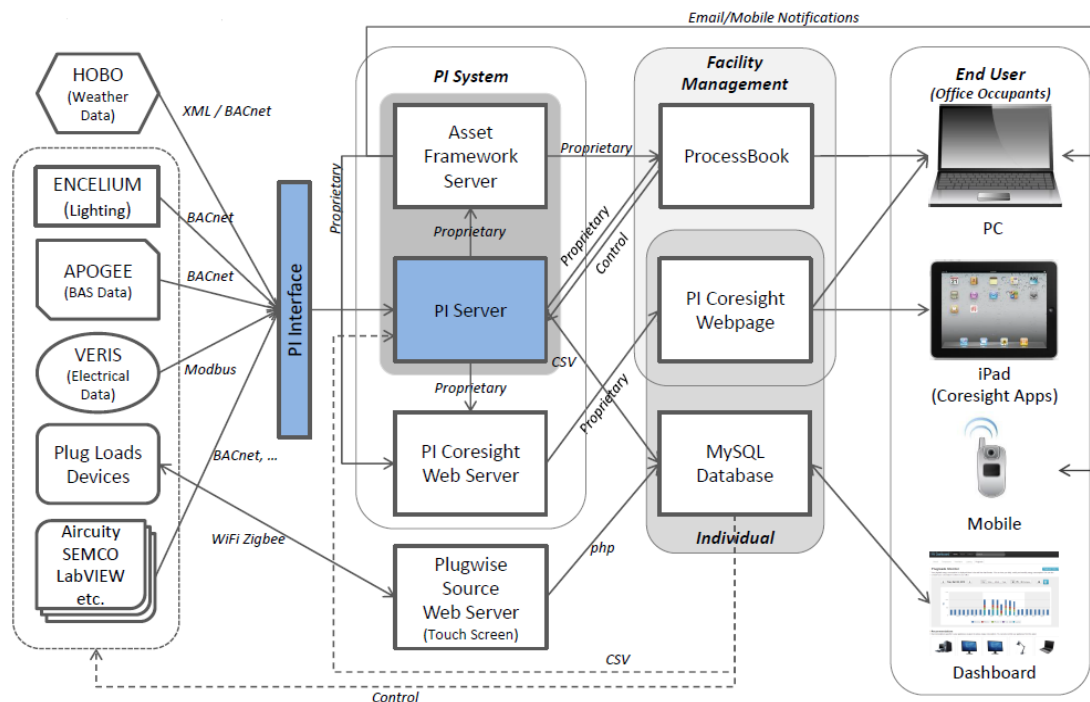
Figure 7. Intelligent Workplace Data Flow Using the OSIsoft PI System

The DOE project in the Intelligent Workplace led to the expanded use of the PI System by the project team to monitor real time energy and BAS conditions in multiple building retrofit projects of the DOE Consortium for Building Energy Innovation (CBEI) in Philadelphia, and most recently in generating a real-time campus database for Carnegie Mellon. This effort is confirming that more than 7 different BAS manufacturers (Siemens, Automated Logic, Johnson Controls, American Automatrix, Delta, KMX, and Carrier.) can be integrated into a common platform using the PI Server, a feature that is of potential significance for other DOD bases with multiple legacy BAS systems.

Plugwise™ is a plug-load energy monitoring technology with significant field presence. The ID-O interface was initially developed by building directly onto Plugwise's integral database, but it is now being moved to the SQL database to ensure that all data sets are in the same flexible setting for integrated decision making. As previously mentioned, the ID-O dashboard was developed over a 2-year period to bring Plugwise electricity metering information more vividly accessible to building occupants and to engage occupants in energy saving control options – achieving measured success in a major corporate headquarter building.

2.3   ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGIES

Performance Advantages:

The PI system will support long-term data acquisition and storage for the DOD base without overwriting due to space limitations or ongoing fees for data retrieval and trending. The ID-F interface will help the facilities team quickly identify and correct energy waste to reduce overall building energy (electric and gas) consumption by 30%.

Through occupant awareness of the energy use of their desktop technologies, and by using online and automated control, the ID-O is expected to reduce plug load electrical energy consumption by 30%.

Cost Advantages:

Since the PI and ID-F platform is a software-based solution, the primary costs will be attributable to engineering and customization efforts such as the development of an ID-F interface specific to the installation. To help minimize user training costs, the interfaces are designed to be intuitive for the facility team to operate. The Return On Investment (ROI) is expected to be within 1 year, if the military installation already has a current PI system license and an operational BAS. Without an active PI system license, the return of investment is expected to be within 2-3 years.

Performance Limitations:

The ID-O and ID-F technologies require careful deployment planning to reduce cybersecurity issues. The project team conducted a cyber-security workshop on December 2014. The workshop included military personnel from the PaANG installation to strategize on methods to reduce potential system hacking and compliance with existing DOD standards. The solution selected was to assign the ID-O and ID-F deployments within the VLAN, separate from the secure NIPRnet. The interfaces of the ID-O and ID-F are designed to be user friendly, so that users will become engaged in collaborative energy conservation and preventative maintenance. Installation of the ID-O and ID-F dashboards on the computers used for work, instead of a separate laptop, as was provided for the demonstration – and/or installation of the dashboards as a mobile app – would enhance the performance by military personnel to align with the results achieved in a civilian environment. DOD and base-specific policies for IT management may also prevent the optimization of the technologies relative to installations in civilian settings.

Cost Limitations:

The collection and analytics platform relies on operational BAS and sub-metering systems within the military installation. The proper mapping of the existing sensors and meters is crucial for seamless integration into the data platform. Another potential added cost that may be incurred during deployment of the technology concerns the reliability of the sensors and utility meters that are installed. Faulty and malfunctioning sensors and meters need to be replaced to ensure robust assessment of the energy and indoor environmental conditions of the facilities. Consequently, re-commissioning of the building is essential for the proper installation of the demonstrated technologies. Although re-commissioning can be an expensive process, depending on the state of the building, such necessary work almost invariably pays for itself within the first year of the technology's use.

Potential Barriers to Acceptance:

The ID-O technology was widely accepted at previous pilot test and demonstration sites, as it provides an easy-to-use and user-friendly interface for building occupants to manage their plug load usage. The interface provides users the ability to control their appliances (turn ON/OFF), view energy consumption in multiple formats at selected intervals, provide expert feedback based on the occupant's specific consumption, and provide an automation feature tied to the occupant's schedule. A potential barrier to acceptance of the ID-O within the DOD is the need to install the technology on a separate tablet instead of on the main computer that the occupant uses for his/her daily tasks. The deployment of the technology on a separate hardware device is necessary to ensure network security (VLAN vs. NIPRnet). However, the separate hardware may reduce the interaction between the building occupant and the plug load management dashboard.

Similarly, the ID-F must be installed on dedicated hardware, thereby eliminating the mobile friendly version of the dashboard for facilities personnel who are moving about the base. The PaANG installation (similar to most military installations) is not equipped with a wireless network.

3.0   PERFORMANCE OBJECTIVES

The technology and economic Performance Objectives (PO) focused the measurement of the technology's contribution to DOD energy goals and demonstrated efficacy of the system for deployment at military installations.

- Energy Savings: The performance objectives measured the reduction in energy use achieved after installation of the technology in comparison with an annual baseline established prior to deployment of the system. The results are attributable to a combination of advanced real-time monitoring and increased user engagement. Installation of the technology also lead to improved metering and measurement of energy usage with advanced electrical and gas metering.
- Greenhouse Gas Reduction: The performance objectives measured the reduction of GHG emissions as a result of decreased energy consumption.
- User Engagement Toward Sustainable Practices: The performance objectives measured the active engagement from Occupants and Facility Managers in sustainable behavior by using the ID-F and ID-O dashboards.

3.1   SUMMARY OF PERFORMANCE OBJECTIVES

Table 2. Performance Objectives

Performance Objective	Metrics	Data Requirements	Success Criteria	Results
Quantitative Objectives				
Reduce Overall Building Energy Consumption (ID-F)	Energy Intensity (MMBTU/^{ft2} kWh/ft^2)	Real-time metered and historical energy data and building square footage	> 30% annual energy savings	**Not Achieved 10% Savings**
Reduce Plug Load Energy Consumption (ID-O)	Energy Intensity (kWh/ft^2)	Energy consumption data from plug load meters, building square footage	> 30% annual plug load energy savings	**Not Achieved 24% Savings**
Reduce Greenhouse Gas Emissions (GHG)	Emissions from fossil fuel (metric tons of eCO$_2$)	Estimated GHG based on measured or historical energy data	> 30% annual GHG reduction	**Not Achieved 10% Savings**
Favorable System Economics	Simple Payback (years)	Calculated or estimated energy saving in dollars, system first costs	Payoff in < 3 years for ID-F Payoff in < 5 years for ID-O	**Achieved**
Level of Technology Transfer, deployment, and applicability	Number of DOD installations which could use the system	Comparative analysis of Technology applicability at similar military bases using surveys and literature reviews.	Technology applicable to more than 25% of DOD bases	**Achieved**

Table 2. Performance Objectives (Continued)

Performance Objective	Metrics	Data Requirements	Success Criteria	Results
Qualitative Objectives				
Positive Occupant Behavior Change	Active participation in energy conservation	Energy conservation awareness survey data, logged interaction with dashboard	# of recommendations followed by occupants, increased energy conservation awareness	**Achieved 85% of occupants' engagement**
Increase in Occupant Satisfaction	Degree of satisfaction	Occupant survey data	Increased comfort and satisfaction with thermal comfort (pre-versus post-intervention)	**Achieved**
Provide Enhanced Fault Detection	Number of failures detected	Quality control on critical HVAC equipment. Number of failures detected, number of false positives indicated	Reduced number of complaint calls	**Achieved**
Ease of system use by FM and building occupants	Interaction with introduced technology	FM survey data, interaction with dashboard	More than 80% user satisfaction	**Achieved 85% Satisfaction Level for ID-O**

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

3.2.1 Reduce Overall Building Energy Consumption

The multiple buildings on the campus of the 171st Air Refueling Wing, Pennsylvania Air National Guard ("PaANG") have measurable opportunities for HVAC energy savings. The fusion of building automation and sub-metering inputs with the ID-F portfolio energy management system and facility manager interfaces was evaluated by ongoing energy efficiency gains.

Purpose: The performance target was to achieve up to 30% HVAC energy savings by using continuous monitoring and diagnostics for multiple PaANG facilities, supported by energy metering and BAS data, and providing customized interfaces for facility managers. Energy efficiency had to be met while providing a healthy, productive, and comfortable environment for the building occupants, and reducing operating and equipment costs for the building owners.

Metric: The annual energy metric used to measure this performance objective was the measurement of electricity and gas used on the site, combined in a kBTU/sqft site EUI index.

Data: Data collected from the buildings' automation systems and sub-meter readings of energy used at the installation, as well as consumption recorded by utilities, supported the

analysis of building energy efficiency. Integrated and coordinated control over heating, cooling and ventilation was required.

Analytical Methodology: The impact of the ID-F for facility managers was tested in the field over a 6 months period to capture seasonal variations following a 10-month measurement period that established a baseline for annual energy use. From the 6 months of multi-season data, annual energy savings were calculated through statistical analysis.

Success Criteria: 30% annual savings for HVAC energy use.

Achievement: **Not achieved. Energy reduction reached 10%.** For details, please refer to Section 6.1

3.2.2 Reduce Plug Load Energy Consumption

PaANG-205 (Civil and Engineering Department) and PaANG-110 (Base Supply) have dynamic occupancy and measurable opportunity for plug load energy savings. The introduction of plug load monitoring with the ID-O system and occupant interface was evaluated by ongoing energy efficiency gains.

Purpose: The performance target was to achieve up to 30% plug load energy savings in offices by installing workstation sub-metering and providing customized interfaces for occupants. Occupant participation was pursued for energy conservation in lighting and plug loads which are not controlled by the BAS system. Energy efficiency was to be achieved while providing a productive and comfortable environment for the building occupants and reducing operating and equipment costs for the building owners.

Metric: The annual energy metric used to measure this performance objective was the measurement of electricity used at the workstation, captured in kW, kWh and kWh/sqft (EUI) indices.

Data: Electricity usage and on/off data collected from the sub-meters supported the analysis of workstation energy savings.

Analytical Methodology: The ID-O platform was developed to support occupants in achieving maximum energy efficiency through energy use information feedback, controls and recommendations. The impact of the ID-O for occupants was tested in the field over a 9-month period with a 6-month baseline energy use measurement period. From 3 months of measured energy savings, annual energy savings were calculated through statistical analysis.

Success Criteria: 30% annual savings for plug load energy use.

Achievement: **Not achieved. Energy reduction reached 24%.** For details, please refer to Section 6.2

3.2.3 Reduce Greenhouse Gas Emissions

Based on EPA standards, Scope 2 emission savings were calculated based on the measured energy savings at PaANG to determine the greenhouse gas (GHG) reductions attributable to the

demonstration project. Scope 2 emissions are indirect GHG emissions resulting from the generation of electricity, heating and cooling, or steam generated off-site but purchased by the entity, and the transmission and distribution (T&D) losses associated with some purchased utilities (e.g., chilled water, steam, and high temperature hot water).[1] http://www.epa.gov/oaintrnt/ghg/

Purpose: The concentrations of greenhouse gas emissions in the atmosphere is increasing due to human activity which is causing serious climate changes that affect the environment and natural resources across the globe. If the two performance objectives are achieved - optimizing building energy efficiency and reducing facility peak energy demand - a reduction of direct GHG will result.

Metric: While metric tons of CO2 were the primary focus of the Scope 2 greenhouse gas emission savings from the ID-F investment for portfolio energy management and ID-O investment for desktop energy management, the research team also considered the other major greenhouse gases: methane, SOX, NOX, HFCs, and PFCs.

Data: The fuel mix of electricity delivered to the 171st Air Refueling Wing, Pennsylvania Air National Guard ("PaANG") was the primary consideration for GHG reduction calculations.

Analytical Methodology: ID-F and ID-O are designed to integrate building occupants in the energy efficient control of building subsystems. The electricity and fuel energy savings from these collaborative controls have a direct impact on greenhouse gas reductions. The EPA Energy Profiler and "eGrid" database was used to calculate fuel source mix, source emissions, and transmission and distribution losses.

Success Criteria: 30% reduction in greenhouse gases (GHG) was expected, directly correlated to reduction in energy consumption, with additional benefits expected from peak load reductions.

Achievement: **Target not achieved**. For details, please refer to Section 6.3.

3.2.4   System Economics

The DOD estimates that it spends as much as $4 billion annually on energy related costs for its facilities. The ID-F portfolio energy management system and user interface is an approach that applies intelligent operational strategies to save electricity and fuel consumption in buildings with automation systems. The cost of the ID-F and ID-O hardware and software installation, training, operations, and maintenance must meet the payback criteria of the DOD to move from demonstration status to implementation at multiple sites.

Purpose: To demonstrate that the ID-F and ID-O energy savings benefits outweigh the installation and operating costs, for widespread adoption in DOD buildings with BAS systems.

Metric: System installation and operational costs in dollars; annual and peak energy savings in kWh and dollars; return on investment in %; payback in years; and net present value of investment (NPV) given a fifteen-year life cycle.

Data: The data required to complete the analysis of the ID-F payback included calculated annual and peak energy savings, utility/fuel costs, and estimates of market-ready equipment, installation, training, operational, and maintenance costs.

Analytical Methodology: The project team developed simple paybacks calculations.

Success Criteria: ID-F was expected to enable 30% energy cost savings with simple payback within 2 to 3 years based on the cost of implementing ID-F. ID-O energy cost savings depended on the market development of low-cost plug meter/controllers; at present, the expected payback period is 3-5 years.

Achievement: **ID-O Success criteria achieved with a 5-year payback period in the case of a full-scale deployment**. **ID-F Success Criteria Achieved.** For details, please refer to Section 6.4.

3.2.5   Level of Technology Transfer, Deployment and Applicability

One additional quantitative metric was the identification of the number of DOD installations that can deploy the ID-F for comparable energy savings.

Purpose: To demonstrate that the ID-F platform is viable for widespread adoption in DOD buildings with BAS systems and building sub-metering.

Data: Analysis of technology applicability at military bases based on comparable BAS infrastructures and electric sub-metering installations.

Success Criteria: Technology applicable to more than 25% of DOD bases, to be quantified through records of BAS and metering efforts at US bases, as available.

Achievement: **Target achieved**. For details, please refer to Section 6.5

3.2.6   Occupant Engagement and Behavioral Change

Given the growing number of electrical loads in today's offices, occupant engagement and behavioral change has proven to be critical to reducing energy consumption in facilities.

Purpose: If occupants actively change their behavior to reduce energy waste while maintaining or improving functionality and comfort, then we can positively quantify the influence of behavior on specific energy end uses.

Metric: Occupant behavior will be evaluated based on the number of occupant interactions with the ID-O dashboard, the number of energy efficient recommendations occupants follow, and the energy savings that result, evaluated against the baseline energy use. At the beginning and end of the test period, occupants were surveyed to establish their energy awareness and their interest in changing behaviors for the long term.

Data: Review of frequency of use of the ID-O interface by office occupants including online occupant control of individual and grouped technology on-off control, calendar control, and

ID-O recommended actions for plug load management. Energy awareness survey responses during and after the ID-O intervention study were also collected.

Analytical Methodology: Correlating occupant engagement with the ID-O dashboard and energy use; correlating energy conservation awareness with frequency of ID-O dashboard engagement.

Success Criteria: Multiple interactions with the ID-O dashboard and sustained savings over a three-month period. Statistically significant changes in energy use awareness surveys completed before and after the ID-O dashboard study period.

Achievement: **Target achieved**. For details, please refer Section 6.6.

3.2.7 Occupant Comfort and Satisfaction

Occupant Comfort and Satisfaction with thermal and air quality conditions is linked to complaints and requests for additional HVAC energy use. The ability to enhance communication and control of environmental conditions at the facility management level, as well as monitor and control workstation energy use at the occupant level, improve comfort and satisfaction as well as save energy.

Purpose: All strategies to save energy should maintain or even increase occupant comfort and satisfaction with indoor environmental quality.

Metric: User Satisfaction Surveys covering the full range of indoor environmental quality metrics were deployed before and during the ID-F interventions. Using a seven-point scale, the percent satisfied, neutral, and dissatisfied and the relative scores captured occupant comfort and satisfaction.

Data: Short on-site user satisfaction surveys (COPE) were taken before and during the ID-F intervention. The 35-question survey provided demographic and IEQ satisfaction data.

Analytical Methodology: All findings were compared to two previous COPE2 surveys undertaken at PaANG as well as the national database that CMU has been building on IEQ satisfaction in the workplace (NEAT database).

Success Criteria: Measured improvements in occupant satisfaction with the environmental variables controlled after ID-F and ID-O deployment, compared to the baseline.

Achievement: **Target achieved**. For details, please refer to Section 6.7.

3.2.8 Facility Manager/Operators Enhanced Fault Detection

Improvements in the quantity and quality of energy management information in the building portfolio database, and available to facility managers through flexible interfaces, upgrades quality control for critical HVAC equipment, speeds failure detection, avoids false positives, reduces occupant complaints and facility management time to address identified problems, and ensures greater operator success in maintaining comfort while reducing energy consumption.

Purpose: To assess the benefits of the ID-F portfolio energy management database and the efficacy of the interfaces available to facility managers to access actionable information from the database. To evaluate the extent to which the technology improves quality control for critical HVAC equipment, speeds up failure detection, avoids false positives, reduces occupant complaints and facility management time to address those complaints.

Metric: Reduction in duration of fault detection, reduction in false positives, and reduction in complaint calls to facility management.

Data: Online records of duration of faults and false positives before and after installation of ID-F, FM records of number of complaint calls.

Success Criteria: Percentage of reduction in duration of fault detections (early warning), number of false positives, and number of complaint calls.

Achievement: **Target achieved**. For details, please refer to Section 6.8.

3.2.9   Ease of System Use by FM and Building Occupants

The development of the ID-F campus BAS/Energy dashboard and the ID-O plug energy dashboard represents a third generation of interfaces with feedback from the PaANG end users.

Purpose: To assess the ease of use of the ID-F portfolio energy management database through the facility manager interfaces and the ease of use of the ID-O workstation plug energy interface.

Metric: Frequency and depth of dashboard use, recorded as number of clicks to different pages, before and after user interviews that support refinements.

Data: Dashboard clicks to different pages recorded for the duration of the ID-F and ID-O test period.

Analytical Methodology: Number of clicks per interface page will be recorded over time. The facility managers and occupants will be interviewed, and recommendations for improving ID-F for broader application will be gathered and documented.

Success Criteria: Building occupants and facility managers express desire to continue using the software.

Achievement: **Target achieved**. For details, please refer to Section 6.9.

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4.0 FACILITY/SITE DESCRIPTION

The selected facility was the Pennsylvania Air National Guard (PaANG), 171st Air Refueling Wing base in Coraopolis, PA. The PaANG campus is adjacent to the Pittsburgh International Airport, which is approximately 18 miles from downtown Pittsburgh, PA. This site hosted an earlier ESTCP field demonstration project (EW-201366), led by Siemens Corporate Technology, that ended in March 2014.

4.1 GENERAL FACILITY/SITE SELECTION CRITERIA

Geographic Criteria:

The technology demonstrations are independent of climate zone, geography, building type, BAS type and instrumentation, sub-metering technologies, and sources of energy supply. Consequently, the characteristics of the installation are representative of DOD military installations throughout the world.

Facility Criteria:

The demonstration project requires a military installation with existing BAS systems that control the buildings' mechanical and electrical equipment. Because the data collection and monitoring infrastructure for the ID-F is vendor agnostic, the BAS and sub-meters can be from multiple vendors using different communication protocols.

The demonstration started with the collection of baseline data from the various BAS, sub-meters and other sensors deployed within the installation. For the ID-O, the project team deployed plug load smart meters to collect energy consumption profiles for office electrical appliances.

Facility Representativeness:

The selected PaANG installation is representative of other military installations because they have similar building types (i.e. offices, warehouses/storage and workshops). As an Air Force National Guard installation, it also accommodates hangar buildings and runways.

Other Selection Criteria:

The PaANG installation is located approximately 22 miles from Carnegie Mellon University's campus, making it very convenient for the CMU team to administer and monitor the technology deployment. Additionally, due to a previous ESTCP demonstration project (EW-201366), the project team has excellent relationships with PaANG personnel.

4.2 DEMONSTRATION FACILITY/SITE LOCATION AND OPERATIONS

Demonstration Site Description:

There are a total of 40 buildings/structures and five major building types within the PaANG installation (see Table 3). The five major building types at the installation are 1) Offices 2) Hangars 3) Workshops 4) Warehouse/Storage Buildings and 5) Miscellaneous Buildings/ Structures that occupy a total area of approximately 400,000 square feet. Hangars have the highest square footage at more than 168,000 square feet, representing 42% of the total building floor space, followed by offices at 108,000 square feet (27%). Information is collected from approximately 4,600 data points (utilities and BAS) at the installation. Most of these points are located in office buildings; they account for more than 70% of the total number of data points on the base.

Table 3. Building Type and Monitored Areas

Function	#	Area		# of data points	
		Sqft	%	Sqft	%
Offices	8	107,579	27.0%	3,254	71.0%
Hangar	4	168,249	42.2%	591	12.9%
Workshop	4	46,266	11.6%	324	7.1%
Warehouse/Storage	7	60,243	15.1%	104	2.3%
Misc. Buildings/Structures	17	16,541	4.1%	310	6.8%
TOTAL	40	398,878		4,583	

Table 3 above provides a breakdown by function for the various buildings and structures within the installation, and Table 4 below provides a detailed description of the locations for major HVAC equipment components. The major equipment types include AHUs, RTUs, boilers, and chillers. There are 8 AHUs, 4 RTUs, 5 boilers and 2 chillers. Most of the mechanical equipment is located in the office and hangar buildings.

In addition, the base is equipped with several building-level analog and digital meters for gas, electricity, and water. There are 16 electric sub-meters (5 analog and 11 digital), 9 gas sub-meters (4 analog and 5 digital), and 9 water sub-meters (all analog).

Table 4. Distribution of Mechanical Equipment and Utility Sub-metering

Building #	Function	Area	# of data points	Equipment Types					Submetering		
				AHU	MAU	Boiler	Chiller	RTU	Electricity	Gas	Water
		27.0%	71.0%								
	OFFICES	107,579	3254	6	0	3	2	4			
BLDG102	Compliance Office, Gym	5,227	N/A						No	No	No
BLDG103	Security Forces	9,157	65	2					Digital	Analog	No
BLDG105	Base Exchange	2,054	285						Digital	No	N/S
BLDG107	Base Operations	31,463	1,351	1		1	1	1	Digital	Digital	No
BLDG205	Civil Engineering	13,156	18			1		1	Digital	Analog	Analog
BLDG300/D	Base Headquarters/Dining Hall	43,787	1,444	1		1	1	2	Digital	Digital	No/N/S
BLDG402	Remote Flightline Office	219	N/A						No	N/S	No
BLDG410	Alert Crew Readiness	2,517	91	2					Digital	Analog	Analog
		42.2%	12.9%								
	HANGAR	168,249	591	1	0	1	0	1			
BLDG301	Maintenance Hangar	50,415	N/A						Digital	Digital	No
BLDG302/A	Maintenance Hangar/Comm Squadron	65,883	369					1	Digital	Digital	No/No
BLDG304	Fuel Cell Hangar	25,944	176						Digital	Digital	No
BLDG320	Fuel Cell Hangar	26,006	46	1		1			Digital	Digital	Analog
		11.6%	7.1%								
	WORKSHOP	46,266	324	8	2	0	0	0			
BLDG308	Metal Fabrication Shop	8,587	80	1	2				Digital	Digital	No
BLDG316	Aircraft Support Equip. Shop & Storage	9,769	26	1					Analog	Analog	Analog
BLDG310	Jet Engine Shop, KC-135 Simulator	16,060	N/A						No	Analog	Analog
BLDG404	Vehicle Maintenance	11,852	218	6					Digital	Digital	Analog
		15.1%	2.3%								
	WAREHOUSE/STORAGE	60,243	104	1	0	1	0	0			
BLDG110	Base Supply/Warehouse	34,997	104	1		1			Digital	Digital	No
BLDG120	Supply Warehouse	3,795	N/A						No	Analog	N/S
BLDG212	C.E. Covered Storage	1,953	N/A						No	Analog	N/S
BLDG305	Comm. Storage	962	N/A						No	N/S	N/S
BLDG307	Non-Power Support Equip.	7,243	N/A						No	No	No
BLDG403	Mobility Storage	5,253	N/A						Analog	N/S	N/S
BLDG405	Vehicle Storage Building	6,041	N/A						N/A	N/A	N/A
		4.1%	6.8%								
	MISCELLANEOUS BUILDINGS	16,541	310	2	0	0	0	0			
BLDG100	Traffic Gate House	92	N/A						Analog	N/S	N/S
BLDG101	Electrical Substation	N/A	45						Digital	N/S	N/S
BLDG104	Traffic Gate House	181	N/A						No	N/S	No
BLDG108	Base Fire Station	4,457	N/A						No	Analog	Analog
BLDG111	Base POL Operations	339	N/A						No	N/S	N/S
BLDG112	POL Hydrant System	345	N/A						No	N/S	N/S
BLDG113	POL Operations	1,654	N/A						Analog	No	Analog
BLDG121	Hazmat	1,513	N/A						No	Analog	No
BLDG122	POL Operations	159	N/A						No	No	No
BLDG200/M	Small Arms Range	N/A	N/A						N/A	N/A	N/A
BLDG206	Weather Flight	3,428	N/A						No	Analog	No
BLDG213	CATM and CATS Facility	2,394	148	2					Analog	Analog	Analog
BLDG215	Laterine	90	N/A						No	N/S	No
BLDG303	N/A	N/A	117						N/A	N/A	N/A
BLDG318	CCTV Equipment Bldg	45	N/A						No	N/S	N/S
BLDG321	Fire supression Pump House	1,800	N/A						No	Analog	No
BLDG401	Traffic Check House	44	N/A						No	N/S	No
TOTAL		398,878	4,583	18	2	5	2	5	5	12	9
									14	9	
									19	21	9

LEGEND

|	
N/A	Not Applicable
N/S	??
26	Analog sub-metering
23	Digital sub-metering

The Pennsylvania Air National Guard (PaANG) refueling station and military installation is comprised of five main building types. The majority of the buildings (73%) have very few occupants on a regular basis. Approximately 27% of the buildings house the majority of PaANG's occupants and personnel (identified in orange in Figure 8). These highly occupied buildings were categorized as office buildings.

Office buildings were selected as the use type in which to install the majority of the sensors (71%), as data collection in these spaces provides the greatest opportunity for energy savings that will directly impact the personnel (see Figure 9). The remaining 29% of the data points were divided among the remaining building use types based on their percentage of energy consumption and personnel occupancy on the base.
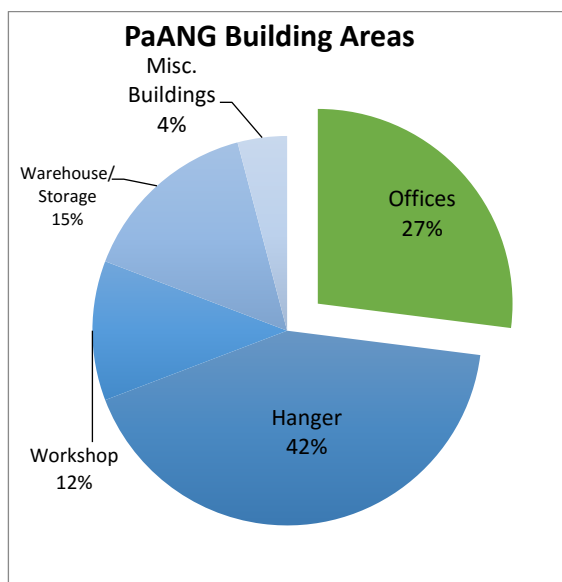
Figure 8. Breakdown of PaANG Building Areas by Building Use Type
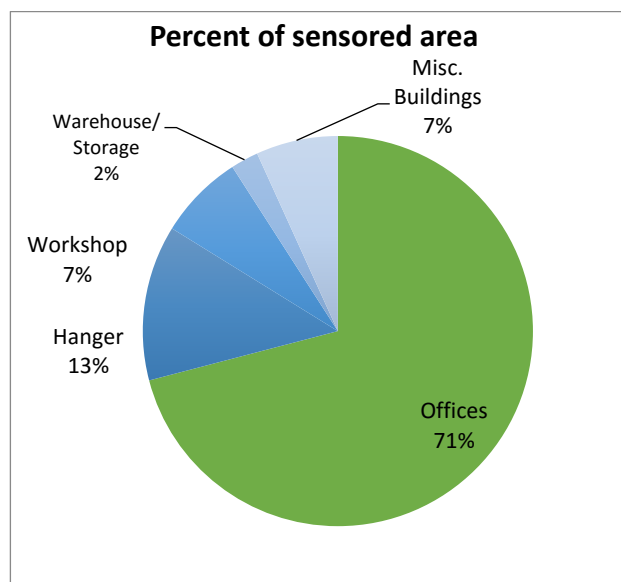
Figure 9. Percentage Allocation of Sensors and Data Points by Building Use Type.

As mentioned previously, buildings classified as "offices" comprise 27% of the total building area on the base. There are eight office buildings on the base that are utilized by PaANG staff. However, 70% of all "office" type spaces are housed in two buildings: Building 300 and Building 107. Because these two buildings have the highest occupancies, they also contain the most sensors and data points.

Table 5. PaANG Office Building Sensor Distribution

Building Number	Function	Area (SqFt)	Number of Data Points
BLDG300/D	Base Headquarters/ Dining Hall	43,787	557
BLDG302	Base Operations	65,882	812
BLDG107	Base Operations	31,463	1871
BLDG205	Civil Engineering	13,156	706
BLDG103	Security Forces	9,157	53
BLDG410	Alert Crew Readiness	2,517	126
BLDG105	Base Exchange	2,054	124

Building 300 houses the base headquarters and a large dining hall. These operations comprise the greatest percentage of office spaces of any building type on the base (40.7%, 43,787 SqFt). Due to the large area of office space, Building 300 has the largest quantity of sensors and data points (1,444 data points).

A large dining hall is located on the first floor of Building 300. While the dining hall encompasses a large area of the first floor, it is utilized infrequently except during reserve weekends when the dining hall receives a tremendous influx of occupants. The second floor of Building 300 includes the majority of the frequently utilized offices.

Weekday operations on the second floor of Building 300 include the Commander's Suite, Operations Planning, Legal, Finance, Recruiting, and Public Affairs. The spaces for these activities include a mix of private offices, office suites with secretarial spaces, open areas with workstations, and a conference room. As a result, the second floor provides a mix of HVAC control zones that serve single occupants (such as for the commanding officer), shared suites (such as for the attorneys), and interacting open areas of desks (such as for the recruiting personnel). Some occupants occupy their assigned spaces on a regular schedule (e.g. finance department), while others have schedules that often require their presence elsewhere within the building (e.g. operations planning) and/or outside the building (e.g. recruiting). Such a dynamic mix of building occupant usage profiles provides a robust test bed for the project.

The second floor of PaANG-300 was the primary test bed for Project EW-201366. Although the HVAC for PaANG-300 serves the entire building and thermal/physical dynamics affects are interactive throughout the structure, measurable delivery of energy through ventilation systems, as well as electrical service, can be effectively isolated for the second floor.

Next in size after Building 300, Building 107 contains the second largest building area of all office buildings on the base (29.3%, 31,463 SqFt). Building 107 houses Base Operations.

The remaining 30% of "office" buildings house a total of 459 sensors and data points. These buildings are noticeably smaller and have smaller occupancy levels.

In addition to "office" type buildings, the PaANG installation includes four other building types: Hangars, Workshops, Warehouses & Storage, and Miscellaneous buildings such as gatehouses and substations.

While the Hangar Buildings encompass 42.2% of the total base building area, Hangar type buildings have small occupancy numbers and only one of the Fuel Cell Hangars has an Air Handling Unit (AHU) and a boiler. The Maintenance Hangar that includes the Command Squadron includes the largest number of sensors and data points of all Hangar type buildings.

Workshop type buildings encompass 11.6% of the total base building area and 7.1% of the project data points. The largest number of sensors was placed in the Vehicle Maintenance building. This building has 6 AHUs connected to the BAS.

Many of the Warehouses & Storage and Miscellaneous-type buildings do not include any sensors and data points. These buildings also do not include major mechanical equipment connected to a BAS. Due to this lack of major equipment and limited occupancy levels, many of these buildings do not include any data points.

The ID-F database and dashboard collected from and communicated with all meters and BAS data for 14 buildings on the base (see building location on base site plan, Figure 10). Early data collection indicates some major anomalies that can be addressed, while longer trended data and data analytics provided more detailed insights.

Location/Site Map:
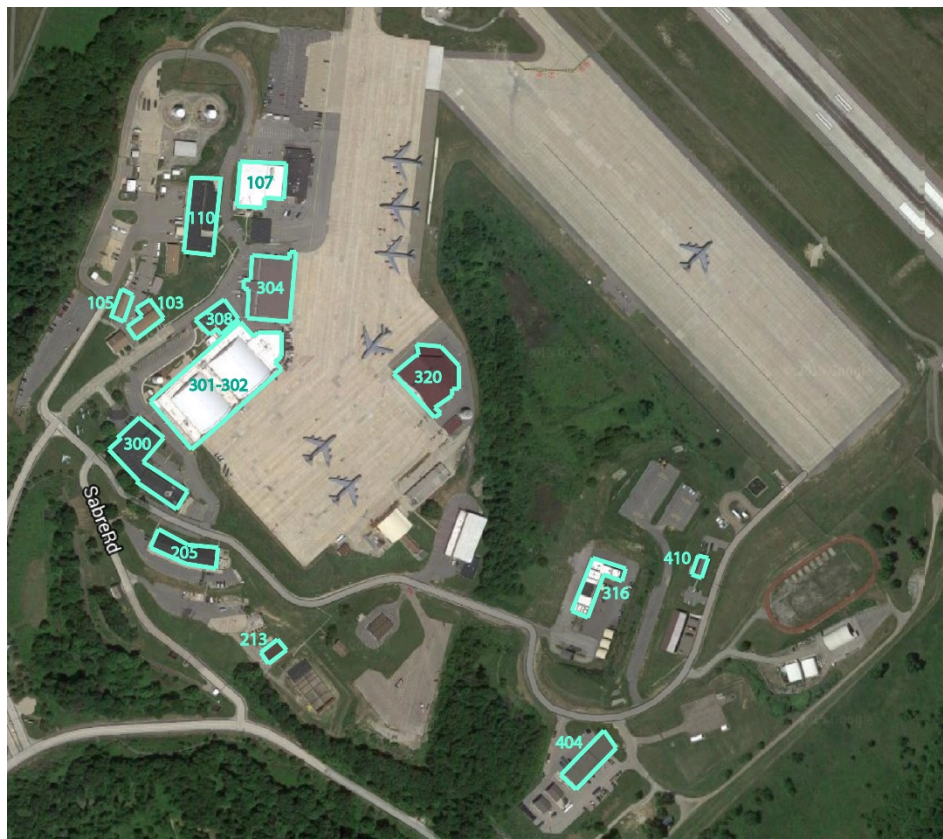
Figure 10. Site Plan of the PaANG Installation, Coraopolis, PA

Other Concerns:

There were no major negative concerns related to the demonstration site.

4.3   SITE-RELATED PERMITS AND REGULATIONS

Regulations and Environmental Permits:

No special permits were required for the technology demonstration. No specific regulations at the federal, state, or local levels of government were applicable to the demonstration project. All permissions from the perspective of military operations and security were obtained by the PaANG military partner for the project; and any concerns that arose with regard to military operations and security were attended to by PaANG through our primary POC, Lt. Col. Joseph Sullivan.

The technology demonstration did not produce any emissions or have any other environmental effects.

Agreements:

The Carnegie Mellon University team obtained approval from the University's Institutional Review Board (IRB) to conduct the demonstration at the PaANG installation. This approval allowed the research team to conduct experiments that involve human subjects. The IRB determined that the experiment protocol would not cause harm to the PaANG personnel.

Siemens SBT coordinated the installation of the sub-,meters for the project with Lt. Col. Joseph Sullivan. The CMU team coordinated the scheduling and deployment of the plug load smart meters with Lt. Col. Joseph Sullivan.

Laptops connected to the VLAN were set up for all building occupants who participated in the ID-O demonstration. The laptops displayed the ID-O dashboard and the occupants were able to view their plug-load energy consumption and control their electrical equipment and appliances via the ID-O interface.

Military Requirements:

The CMU team coordinated with Lt. Col Sullivan to meet any DOD-wide, service-specific, or site-specific requirements, approvals, or waivers that may have impacted the demonstration.

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5.0   TEST DESIGN

Fundamental Problem:

The optimal performance of a building during its lifetime is often compromised due to a lack of monitoring and continuous diagnostics. Drifts or anomalies are not detected, analyzed, and reported. Additionally, various hardware manufacturers produce stand-alone systems and use proprietary communication protocols; and very few robust integrated infrastructure systems are available on the market to integrate them. Furthermore, occupants are not given information regarding their energy consumption and have very little control over their indoor environment. What's more, common building operation practices do not include occupants for feedback and control.

The demonstration aimed to address these shortcomings by implementing an integrated platform solution for monitoring and diagnosing building performances to reduce energy consumption while empowering building occupants toward more energy efficient behavior.

Demonstration Question:

Can the ID-F/ID-O systems be a widely deployable technology capable of reducing annual building and plug loads energy usage by 30% through users' (building occupants and facility managers) engagement in sustainable behaviors while also increasing occupants' satisfaction and comfort?

In this demonstration, the project team compared the campus-wide system as it stood prior to introduction of the demonstration technology with one that uses the integrated platform.

5.1   CONCEPTUAL TEST DESIGN

5.1.1   Hypothesis

The proposed technology enhances the ability of building occupants and base facility managers to become engaged in collaboration toward reducing the energy consumed at the base. To assess the effectiveness of the proposed technology to achieve the performance objectives' success criteria, several tests were designed.

The acceptance criteria for the above hypothesis were:

- 30% reduction in total building energy consumption
- 30% reduction in plug load consumption through user engagement
- Predictive Maintenance through continuous Fault & Diagnostics presentation

5.1.2   Variables

Independent variable(s):

These are the variables manipulated or changed by the facility managers using the ID-F platform and by the building occupants using the ID-O platform.

Dependent variable(s):

These variables were expected to be affected by the proposed technology and were measured (Table 6 & Table 7).

- These Variables were measured: Electrical kWh consumed, peak demand (kW), electricity cost, gas kBtu consumed, greenhouse gas emissions, changes in run times of mechanical systems (air handling units, cooling distribution, ventilation, and boilers), and number of faults detected and resolved.

Controlled variable(s):

These variables were not affected by the proposed solution and, therefore, were held constant between the baseline and the experimental period:

The controlled variables include:

- **Static Variables:** building physical characteristics (size, walls and windows insulation value).

- **Dynamic Variables:** occupancy patterns, lighting system (technology and efficiency of the fixtures), and the HVAC system (technology and efficiency of the core system).

Table 6. Test Design Summary ID-F

Controlled Variables	Independent Variable	Dependent Variables
- Building characteristics (size, set points, etc.) - Mechanical system main hardware characteristic - Weather pattern - Occupancy pattern - Baseline duration	Use of the ID-F technology	- Energy usage for whole building - GHG emissions - Total electricity costs - Occupant comfort - Number of faults detected and fixed

Table 7. Test Design Summary ID-0

Controlled Variables	Independent Variable	Dependent Variables
- Building characteristics (size, - set points, etc.) - Electrical Appliances Specs - Weather pattern - Occupancy pattern • Baseline duration	Use of the ID-O technology	- Plug load energy usage - GHG emissions - Occupant satisfaction

5.1.3 Test Design:

ID-F Technology

The ID-F technology provides a cost effective approach to track energy waste, inefficient modes of operation, and equipment faults of an existing building or a group of buildings by enabling advance monitoring and analytic capabilities. The real time monitoring capability of the tool allowed facility managers to detect costly sequences of operation such as:

- inadequate AHU supply air temperature,
- no setback on thermostat during unoccupied hours,
- system failure leading to energy waste (economizer dampers stuck in Open position),
- very high electrical base load during unoccupied hours (nights and weekends)

The energy savings introduced by the ID-F platform was estimated using the ASHRAE Guideline 14-2002 methodology. The intervention targeted several building sequence of operations at the same time; therefore, the whole building method was selected. The Whole Building Prescriptive path requires a full year of baseline data collection and a full year of intervention data collection; therefore, due to the limited demonstration period (less than 2 years), the Whole Building Performance path was selected instead to quantify the energy savings induced by the proposed intervention.

The Performance path required baseline data collection over the full range of seasonal operation. To match these requirements the baseline was collected for a 10.5-months period, spanned over each seasons.

ID-O Technology

The ID-O technology provides insight to building occupants on how to manage their appliances more efficiently by enabling real time energy feedback and allowing automated controls of the appliances through calendar control. For example, the calendar function allowed occupants to set their appliances to be turned OFF at the end of each day and to come back on each morning at a precise hour. Algorithm analyzed users' electrical consumption trends and created personalized feedback and recommendation.

5.1.4 Test Phases:

The main test phases are described below:

- System Installation and baseline data collection: Collection of the buildings' as-built information, occupancy, BAS data, and energy meter data (electrical and gas).
- Baseline Characterization: Statistical analysis was conducted to analyze the baseline energy characteristics and identify the impact energy consumption has on factors not associated by the technology intervention project (i.e. weather, occupancy, etc.).
- ID-O and ID-F user interfaces deployment and BMS commissioning: This phase included hardware upgrades to the existing BAS system, as needed changes were detected by the system.

- Energy savings measurement and estimation: Test result were compared to the baseline and analyzed

5.2   BASELINE CHARACTERIZATION

5.2.1   ID-F Baseline Characterization

Reference Conditions:

The following data was collected for baseline characterization:

- Electrical demand measured from both automatic digital meters and analog meters.
- Gas demand measured from both automatic digital meters and analog meters.
- Boilers' sensors data (supply water temperature, return water temperature and flow, etc.)
- Chiller sensors data (supply water flow and temperature, return water temperature, etc.)
- Ventilation system sensors data (AHUs supply temperature, static pressure, etc.)
- Mechanical system electrical consumption when available (AHUs, RTUs).
- VAV supply air flow and temperature.
- Indoor temperatures and humidity values.
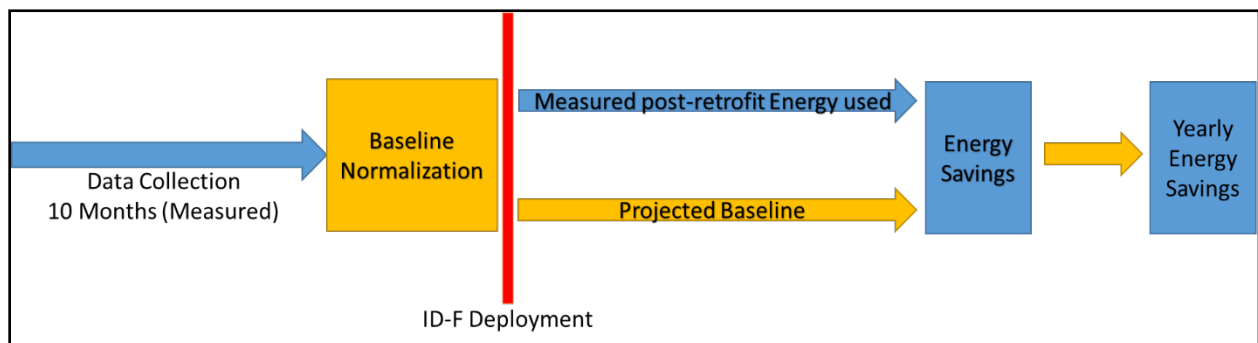- Weather conditions (temperature, humidity, wind speed, wind direction, and solar radiation).

Baseline Collection Period:

Baseline data collection from the PaANG Base electrical and gas meters and building automation systems started in February, 2015. Ten and one-half months of data collection spanning over all climate seasons (February 2015 to December 2015) was performed.

Existing Baseline Data:

The site utility bill for the years 2012, 2013 and 2014 were used to compare main aggregated building level data and assess energy consumption from the base without any sub-meters (see Figure 11).

Baseline Estimation:

**Figure 11. Baseline Estimation for Energy Saving Determination**

Data Collection Equipment:

Table 8. **List of Equipment Used for Baseline Data Collection**

Component	Quantity	Note
PC Server	1	Windows Server 2012 R2, 2.5GHz processor speed, 4 GB memory, 500 GB hard drive

Sensors Point	Status		Note
	New	Existing	
Electrical Building Meters (Digital Meters)	3	8	Meters installed in buildings 205, 105 & 103
Electrical Building Meters (Analog Meters)	0	5	Meter Values to be read manually
Gas Building Meters (Digital Meters)	0	4	No new gas meters were installed for this demonstration project
Gas Building Meters (Analog Meters)	0	5	Meter Values to be read manually;
BAS Sensors Points	0	5000	5000 Data points from BAS

Following ASHRAE Standard 14-2014, regression models were performed for each building to determinate annualized energy savings. A three-parameter regression model for the electrical consumption (miscellaneous + cooling electrical consumption) of building 205 is presented on Figure 12.
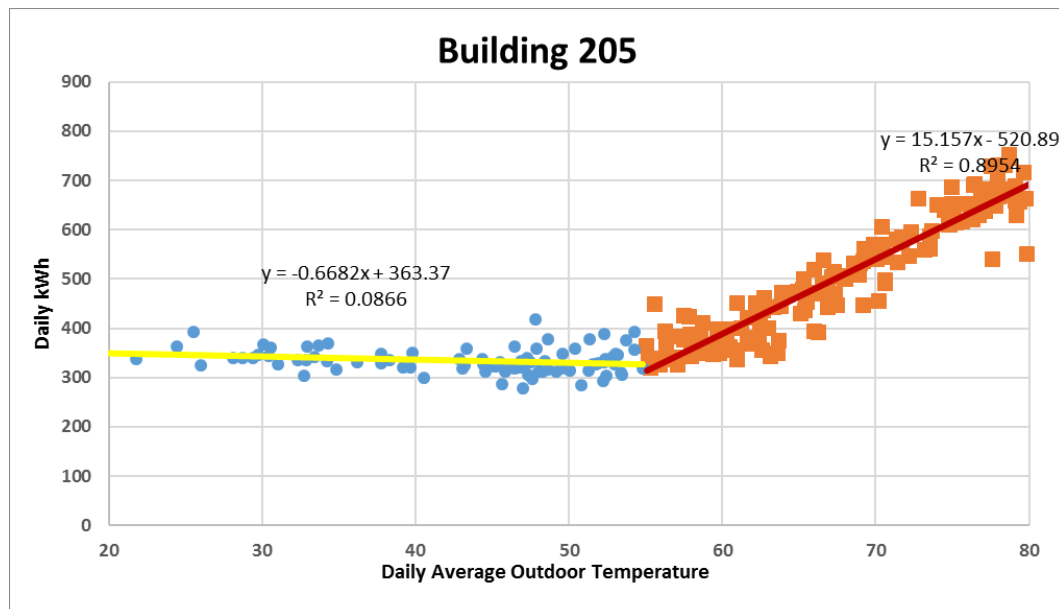
Figure 12. Whole Building Electrical Consumption Regression Model

5.2.2   ID-O: Baseline Characterization

Reference Conditions:

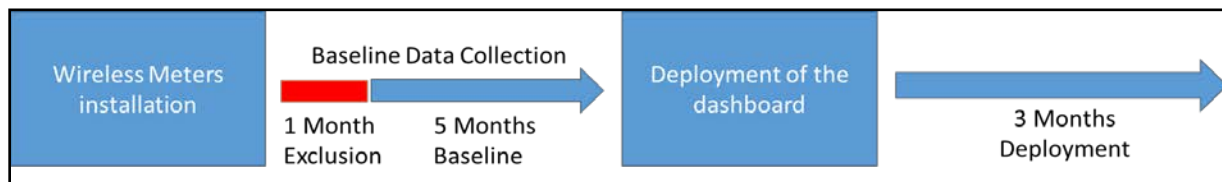The following data was collected for baseline characterization:

- Individual plug load consumption (wireless sub-meters).
- General Base scheduling (reservist weekend)
- Individual Room Occupancy

Baseline Collection Period:

Baseline data collection started in March 2015, after the wireless plug meters were installed on the occupant appliances. Occupants were informed that the meters would record their appliances' energy consumption and were asked not to change their behavior or how they control their appliances. The occupants didn't have access to any energy data information during the baseline data collection.

The first month of data collected was not incorporated to avoid potential "Hawthorne effect" impacts on the data (see Figure 13).

Baseline Estimation:

Figure 13. **Baseline Estimation for Energy Saving Determination**

Data Collection Equipment:

Table 8. List of Equipment Used for Baseline Data Collection

Component	Quantity	Note
PC Server	1	Windows Server 2012 R2, 2.5GHz processor speed, 4 GB memory, 500 GB hard drive

| Sensors Point	Status		Note
	New	Existing	
Wireless Plug Load meters	45	0	Wireless Plug Load meters to be installed on electrical appliances
Occupancy Sensors	0	8	Occupancy Sensors from BAS

5.3   DESIGN AND LAYOUT OF SYSTEM COMPONENTS

System Design:

The ID-F system is a vendor independent software platform that can integrate, extend, and improve existing BAS capabilities by enabling advanced monitoring and analytic tools and by providing fault detection and diagnostics capabilities.

ID-O provides advanced interfaces with which building occupants can control their indoor environment (plug load, lighting system) when digitally addressable systems are available. In this demonstration project, the ID-O system targeted the control and management of plug load appliances.

Figure 14 shows the system architecture of the ID-F & ID-O where the communication between the BAS field Panels and the system is based on the industry standard BACnet. The BACnet interface (adaptor) translates and saves the BACnet UDP packets information in the Time Series database.

The Plug Load energy data collected by the smart wireless meters are managed by the vendor Plugwise Source software. The data is then collected by 2 databases (SQL Server and PI Server).
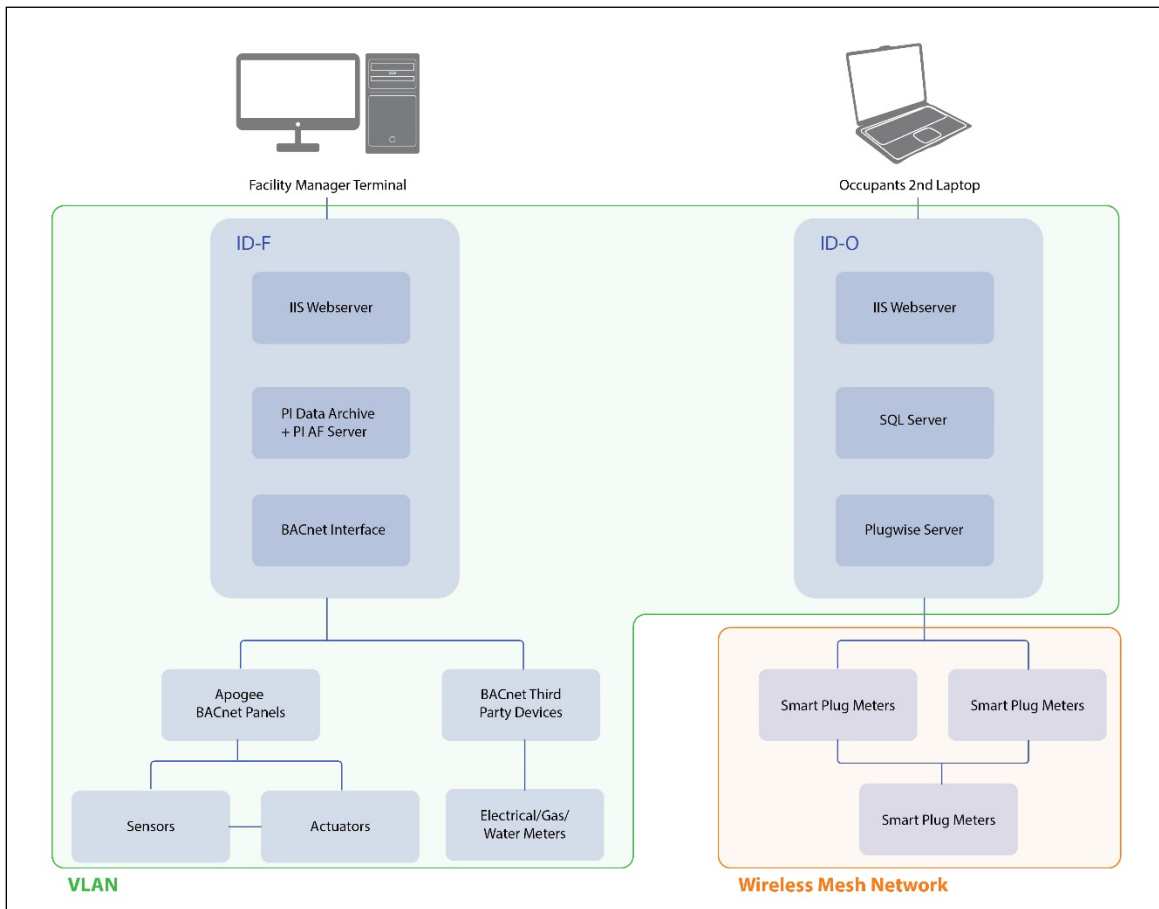
Figure 14. System Layout

39

Components of the System:

A typical setup of ID-F & ID-O installation requires 2 databases (a Time series data base (PI Server) and a relational database (MSSQL Server)), 2 Webservers (IIS webserver), browser-based Occupant Personal Dashboards, browser-based Occupant Public Dashboards, and browser-based FM Dashboards residing in the same network as the existing Building Automation System.

System Integration:

For the demonstration, ID-F was deployed and collected data for each building that had BAS and/or Electrical/Gas meters installed. All HVAC equipment in every building at the base is controlled by an existing Siemens Apogee BAS with BACnet interface

The network setup for the system at PaANG is shown in Figure 14. The facility manager (FM) terminal and occupant terminals reside in the same network with the Apogee BAS, all of which is isolated from other IT network devices using a VLAN. Information outside this closed network can neither come into this network nor go out of it, thereby ensuring separation between the control devices (HVAC and smart meters) from other devices connected to other networks within the office environment.

The FM's terminal is located in the control room where the Apogee Insight server is located. The occupant terminals deployed in Building 205 were made accessible from a second laptop directly hardwired to the VLAN. Both the occupant terminals and the FM terminal were unmodified PCs with Windows operating system that had previously been vetted by the base IT office for purposes of assuring military security.

System Controls:

During the demonstration, the occupants using ID-O were able to control their plug load appliances through the dashboard (see Figure 15). The tool allowed the following features:

a. Automatic calendar control to turn ON/OFF single or a group of appliances
b. Manual ON/OFF control of single appliances
c. Manual ON/OFF control of a group of appliances
d. Appliance-specific recommendations
e. Historical individual appliance power consumption
f. Anonymized peer-to-peer comparison (you, Average, best, among your peers)
g. Effectiveness score
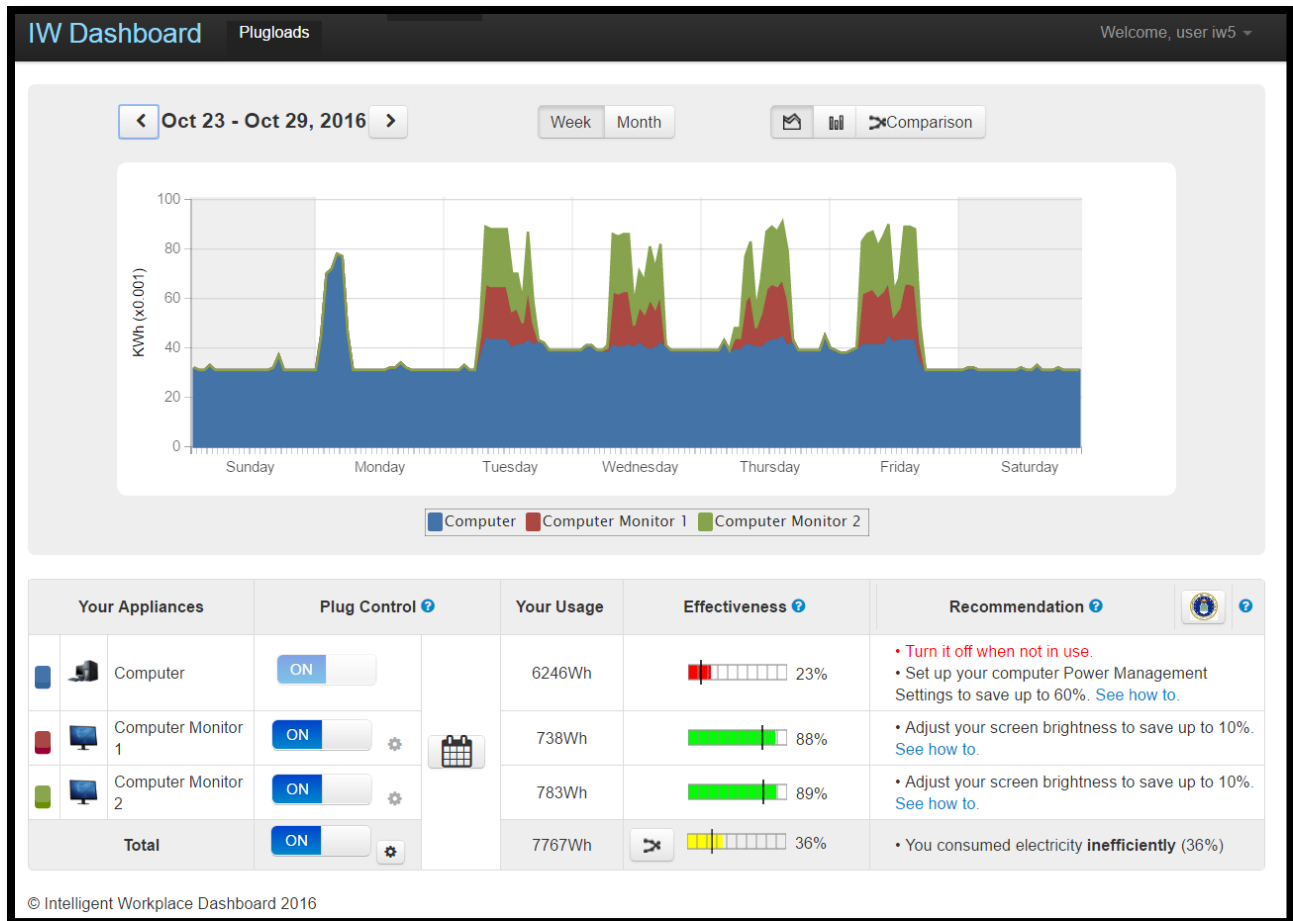
Figure 15. ID-O Display

After discussion with the base Facility Managers, it was decided that the ID-F platform would be deployed in a read-only mode. Anomalies and errors detected by the ID-F platform were displayed to the Facility Manager who could then control/adjust settings on the Siemens Apogee system or troubleshoot field devices.

5.4   OPERATIONAL TESTING

The demonstration was composed of several phases that included: Laboratory Integration, Field deployment and the full demonstration execution. The various data collection process in phase are described below in Table 9:

Operational Testing of Cost and Performance:

Table 9. Operational Testing Design

Phase	Description	Data Collection Process
P1	**Lab Test Integration**	
P1.1	Customization of ID-O technology to DOD IT requirement	CPU Usage, memory usage, data lose, system stability, database performance, system response to user control (latency between command and response)
P1.2	ID-F technology test	CPU Usage, memory usage, data loss, system stability, database performance
P2	**System Installation and Commissioning**	
P2.1	Component and system level testing:	CPU usage, memory usage, latency, data loss
P2.2	System deployment and network installation	% of BACnet points collected and stable, number of data point drops
P3	**Baseline Characterization**	
P3.1	Run the ID-F at PaANG for a 10 months period	Electric meter data, flow meter data, and building automation system trend data, including the sensor and control data for each asset: chiller, air handling unit, VAV box and heat exchangers; occupants survey
P3.2	Run the ID-O at PaANG for a 5 months period	Electrical Appliances data, system stability, Occupancy
P4	**Hypothesis Validation/Demonstration Execution**	
P4.1	Run the ID-F at PaANG for a 6 months period	Electric meter data, flow meter data, and building automation system trend data, including the sensor and control data for each asset: chiller, air handling unit, VAV box and heat exchangers; occupants survey
P4.2	Run the ID-O at PaANG for a 3 months period	Electrical Appliances data, user interaction with ID-O displays

5.5   SAMPLING PROTOCOL

Data Collector(s):

The OSISoft PI Data Archive collects all of the building's time-series data directly from each Apogee BAS field panel and from each individual gas/electrical analog meter. Information from digital meters is manually entered into the system by a field technician with an integrated mobile tool. Facility Managers create routes with a pre-defined list and location of sensors to be collected by the field technician.

For this demonstration project, BAS data was collected using the BACnet protocol. BACnet is a communications protocol for building automation and control networks. It is an ASHRAE, ANSI, and ISO standard protocol. BACnet was designed to allow communication of building automation and control systems for applications such as heating, ventilating, and air-conditioning control, lighting control, access control, and fire detection systems and their associated equipment. BACnet is the protocol used by the PaANG base BAS, but the demonstrated tool is also compatible with other protocols such as Modbus and OPC.
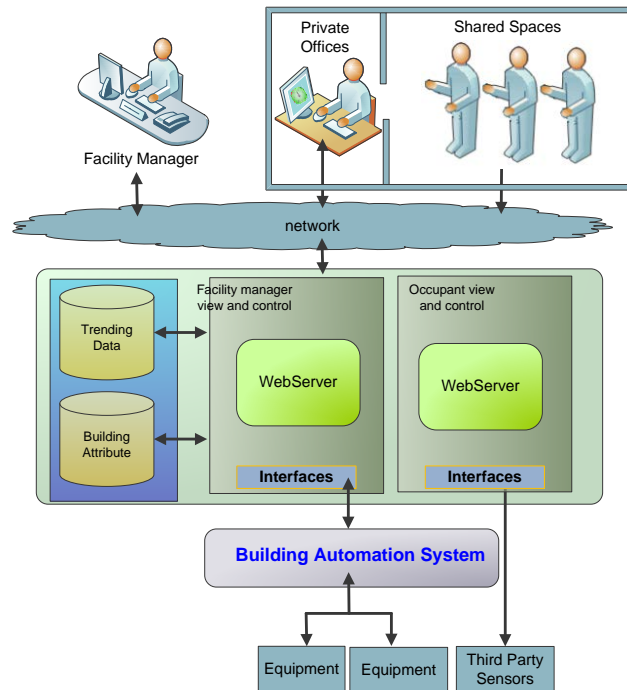
Data Description:

Sensor Data from the BAS were sampled every 5 minutes. Data from the individual electric/gas meters were sampled each minute.

Data Storage and Backup:

The data collected were stored in the OSIsoft PI System time series database. Full backups of the database were performed weekly on an external hard-drive.

Data Collection Diagram:

Figure 16. Data Collection Diagram

Non-standard Data:

Building attributes and mechanical attributes were collected at the beginning of the system implementation and saved in a relational database (OSIsoft AF Database running with Microsoft SQL Server) allowing the software to link each sensor's data to specific assets and their related attributes.

Survey Questionnaires:

See Appendices C, D & E

5.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

Equipment Calibration:

All of the installed monitoring equipment was newly purchased and has a manufacturer's calibration valid for at least the duration of the 22-month demonstration period. Data collected

from these instruments was sufficient to satisfy demonstration performance objectives and meet QA requirements.

All installed sensor functions were checked in accordance with manufacturers' specifications. Following the installation, source-to-data checks were conducted in the field to verify that the data acquisition properly received incoming signals.

Quality Assurance Sampling:

Received sensor data values were monitored to ensure that computed values were within acceptable ranges. Data points were compared against expected variables, and then they were mapped to identify potential outliers that could alert the project team to possible unforeseen anomalies or values outside a realistic range. All checks were documented and stored as part of project files.

Post-Processing Statistical Analysis:

Received sensor data values and data were organized to ensure that the output was understandable, reliable, and within realistic ranges. Additionally, database attributes and labels were made consistent and easily identifiable to ensure the team was able to interpret the data and locate desired sensor outputs.
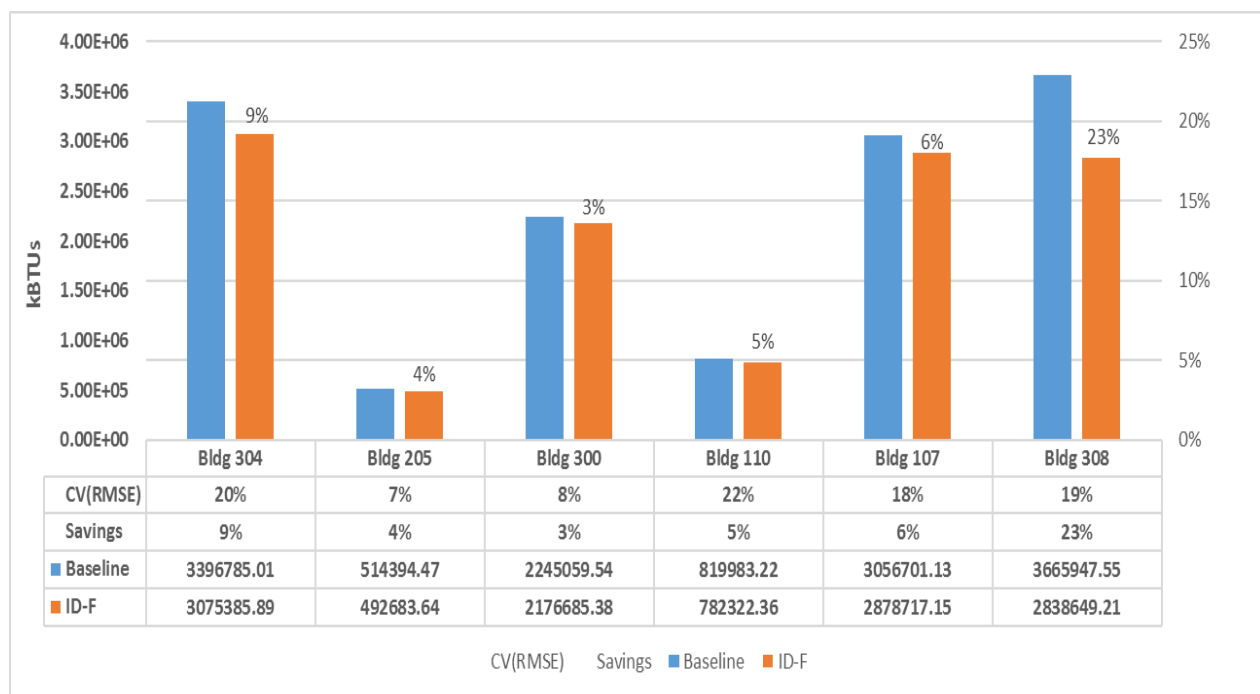
6.0 PERFORMANCE ASSESSMENT

Performance of the ID-F and ID-O technology implementation at the PaANG demonstration site was measured against the baseline to determine energy savings. This performance measurement and verification was conducted following industry best practices established by:

- ASHRAE's Guideline 14-2014 for Measurement of Energy and Demand Savings
- FEMP M&V Guidelines: Measurement and Verification for Federal Energy Projects, Version 3.0 (April 2008)

6.1 PO-I: REDUCE OVERALL BUILDING ENERGY CONSUMPTION (ID-F)

Expected Result**:** The project anticipated achieving a 30% energy reduction in total building energy consumption as measured before and after the deployment of the ID-F technology.

Actual Results: The overall energy consumption savings reached 10%, a result significantly below our target savings of 30%. The energy savings per building ranged from 3% up to 23%.

	Bldg 304	Bldg 205	Bldg 300	Bldg 110	Bldg 107	Bldg 308
CV(RMSE)	20%	7%	8%	22%	18%	19%
Savings	9%	4%	3%	5%	6%	23%
Baseline	3396785.01	514394.47	2245059.54	819983.22	3056701.13	3665947.55
ID-F	3075385.89	492683.64	2176685.38	782322.36	2878717.15	2838649.21

Figure 17. Energy Savings per Building

Energy savings per energy type are presented on Table 10

Table 10: Energy Savings per Energy Type

	Electrical Consumption (kBtu)	Gas Consumption (kBtu)	Overall Consumption
Annualized Baseline	6,197,168	6,743,856	12,941,024
Annualized ID-F	5,866,031	5,747,845	11,613,877
Absolute Savings	**331,136**	**996,010**	**1,327,147**
% Savings	**5%**	**15%**	**10%**

6.2   PO-II: REDUCE PLUG LOAD ENERGY CONSUMPTION (ID-O)

Expected Results: The project anticipated achieving a 30% energy consumption reduction from occupants' electrical appliances as measured before and after deployment of the ID-O technology.

Actual Results:

The overall energy consumption savings reached 24%, close to our target savings of 30%. The highest energy savings per occupant was 34%; and the lowest was an overconsumption of 1%, as seen on Figure 18. Seven out of eight participants saved energy compared to their baseline.
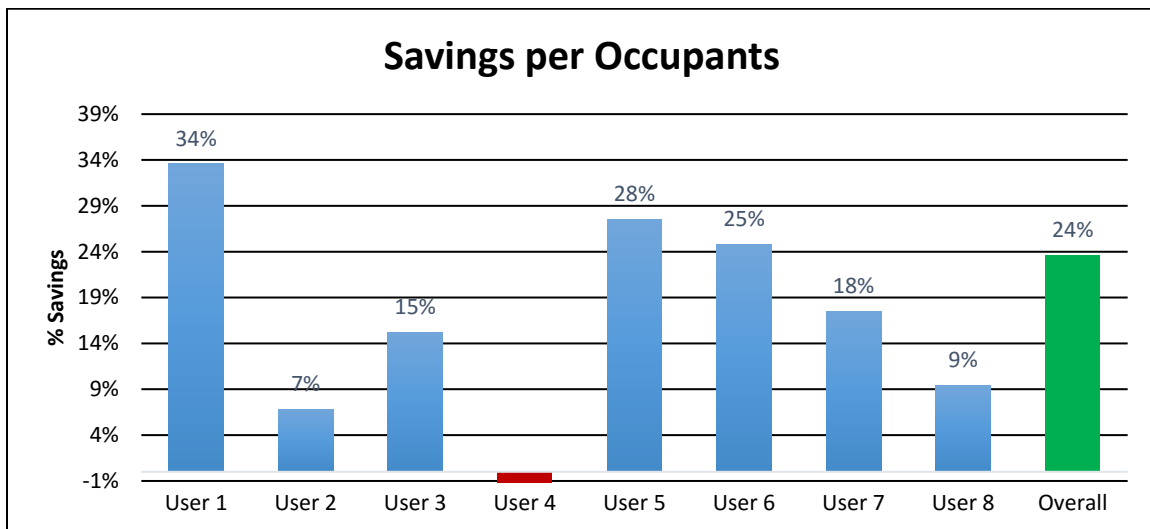
Figure 18. Energy Savings per Occupants

Four main categories of appliances were integrated to the ID-O platform. Median savings per category can be seen on Figure 19. Common appliances (hallway printers, water cooler) had the most energy saving with a median savings of 35%, followed by personal printers (19%), personal monitors (14%) and, finally, personal desktop computers (8%). Personal monitor usage was already efficient at the base because, due to previous training, occupants were correctly managing them. Low savings for personal desktop computers was attributable to a policy that had advised occupants to leave their computers always "ON" in order to be available for automated updates at times when the occupants were absent.
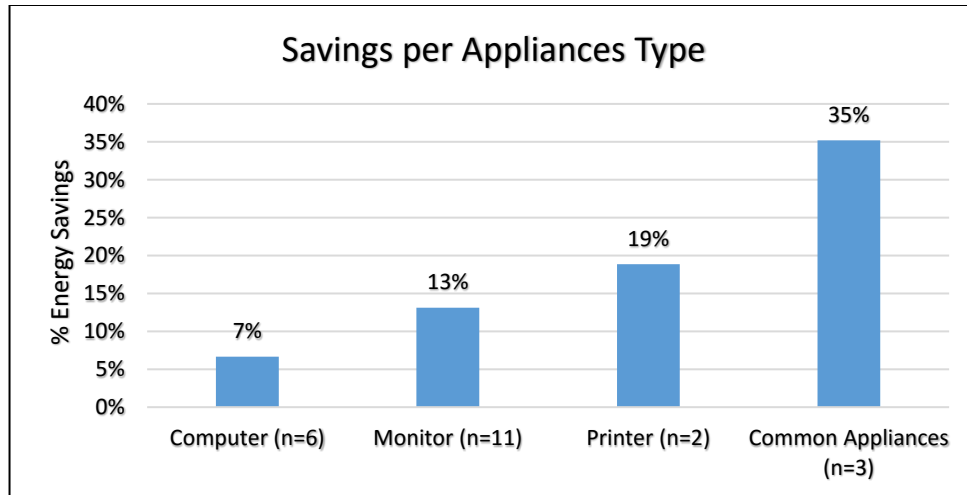
Figure 19. Median Energy Savings per Categories of Appliances

Even though the participants in the study were notified by the base commander that they were allowed to switch off their computers at night, only one of seven occupants changed his behavior and started to turn his computer off during non-work hours on a regular basis (see Figure 20).
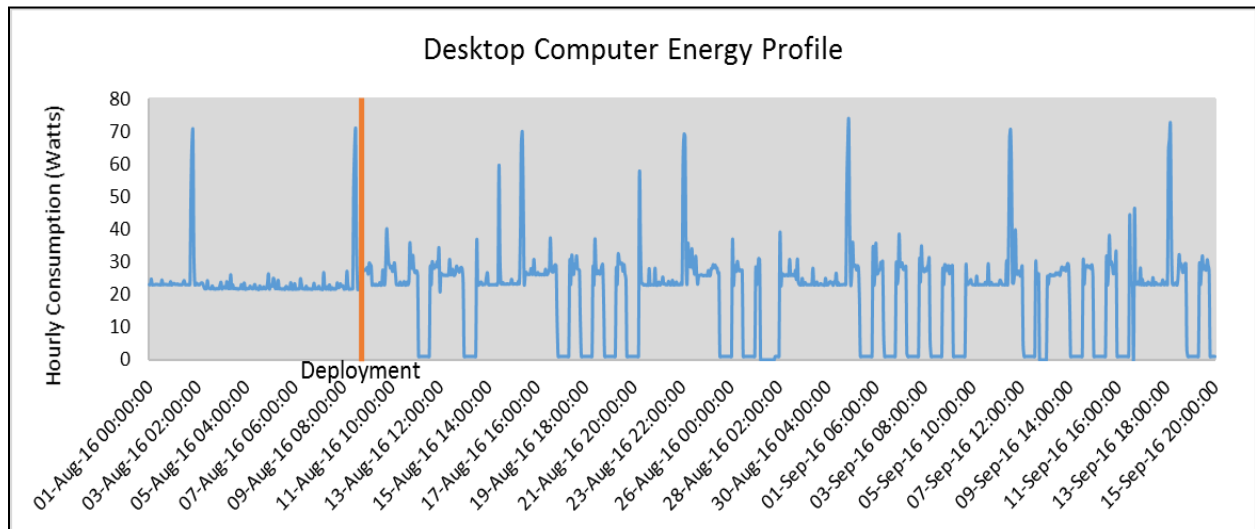
Figure 20. Desktop Computer Energy Profile

As previously explained, a second laptop had to be installed in each office in order to access the ID-O interface running on the base VLAN. Even if the selected installed laptops were energy efficient, it impacted the overall energy savings results. The energy savings decreased six percentage points from 24% to 18% (Figure 21).
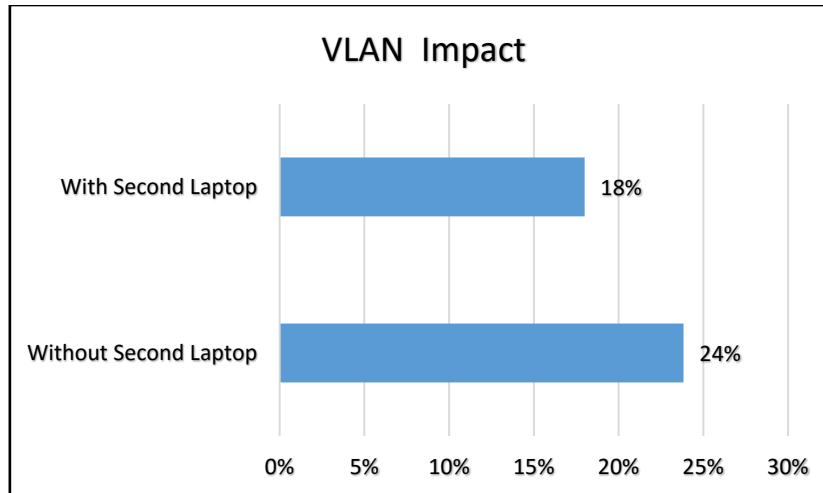
Figure 21. Impact of VLAN Limitation

6.3 PO-III: REDUCE GREENHOUSE GAS (GHG) EMISSIONS

The environmental benefits that are directly linked to electric energy savings relate to the reduction in GHG emissions, particularly CO_2 emissions. The emission factor-based methodology, which estimates GHG emissions by multiplying a level of activity data by an emission factor, has been used to calculate the GHG reduction [9]. Activity data is a quantified measure of an activity; in this case, the electricity and natural gas consumption. The emission factors convert activity data into emission values and are source-specific (see Table 11). The fuel mix of electricity delivered to the PaANG is dominated by coal fired power plants by 58% [10].

Table 11. CO2 Emission Factor – East Region

	Output Rate (lbs/KBtu)	Data Source	Data Year
Electricity			
CO_2	0.470678	EPA eGRID RFCW	2012
Natural Gas			
CO_2	0.116999	EIA	2014

The CO2 emission reduction per technology is presented below in Table 12.

Table 12. Comparison of Emission for ID-O Deployment

|	Baseline Emissions (lbs)	After Emissions (lbs)
ID-O		
CO_2	767.25	584.38
ID-F		
CO_2	3,694,849	3,464,211

48

6.4 PO-IV: FAVORABLE SYSTEM ECONOMICS

6.4.1 ID-O

Table 13. ID-O Savings

Utility Cost	$0.09 per kWh
Annualized Baseline Consumption	5,710 kWh
Annualized Baseline Cost	$ 513
Annualized ID-O Consumption	4,231 kWh
ID-O Technology Cost	$1,100
ID-O $ Savings	$140
ROI	12.7%

The low ROI for this demonstration project is due to the scale of the demonstration deployment. With larger deployments, some fixed cost will be significantly reduced. The payback in years as a function of deployment scale is represented in Figure 22. With deployment for more than 120 employees, the expected payback is less than 5 years (20% ROI).
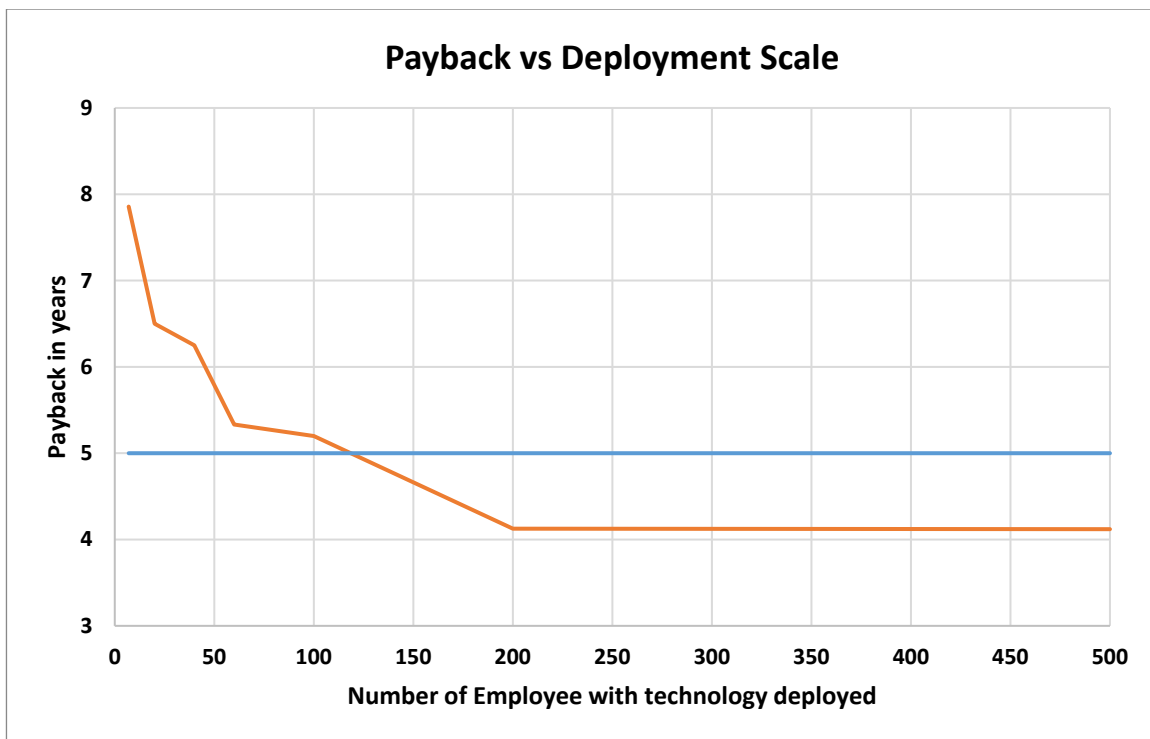
Figure 22. Technology Payback by Deployment Size

6.4.2   ID-F

Table 14. ID-F Savings

	Elect. Consumption	Gas Consumption	Total
Utility Cost	0.09 per kWh	8$ CCF	
Annualized Baseline Consumption	1,816,286 kWh	67438 CCF 1,976,511kWh	3,792,797 kWh
Annualized Baseline Cost	$163,465	$51,113	$214,578
Annualized ID-F Consumption	1,719,235 kWh	67438 CCF 1,684,597 kWh	3,403,832 kWh
ID-F Technology Cost	$55,000		
ID-F $ Savings	$8,734	$6,710	$15,444
ROI	28%		

6.5   PO-V: LEVEL OF TECHNOLOGY TRANSFER, DEPLOYMENT AND APPLICABILITY

The ID-F technology can be deployed to any base where the buildings are controlled by Building Automation Systems from any vendor using an open data communication protocol such as BACnet or providing a front end API.

The ID-O technology can be deployed to any base with office workers where wireless technology (specifically ZigBee) deployment is possible.

6.6   PO-VI: POSITIVE OCCUPANT BEHAVIOR CHANGE

In order to measure occupant participation level, two variables were tracked during the technology deployment.

- Number of time users logged into the system

- Number time users control the appliances using the ID-O Interface

Active users of the system (2 or more times per week) saved energy ranging from 7% to a maximum of 34%. The only user without any interaction with the system overconsumed by 1% compared to baseline (see Figure 23). Seven out of eight participants actively interact with the ID-O technology throughout the demonstration period (3 months deployment).
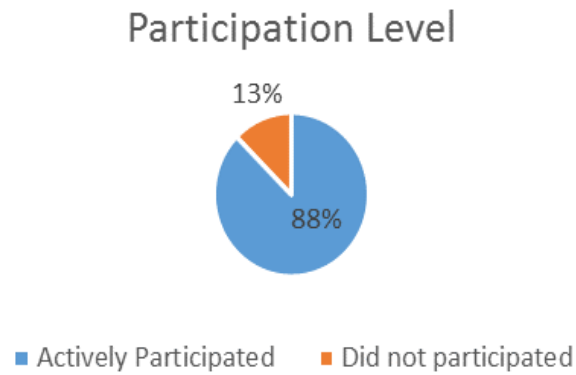
Figure 23. Participation Level

6.7 PO-VII: INCREASE IN OCCUPANT SATISFACTION

The team distributed two user satisfaction surveys, one before the implementation of the ID-F technology (Figure 24) and the other during (Figure 25). Both surveys were performed during heating season. The survey asked questions about thermal, visual, acoustic, and air quality satisfaction levels; but only thermal and air quality question results were analyzed, as the ID-F can only impact these two attributes.
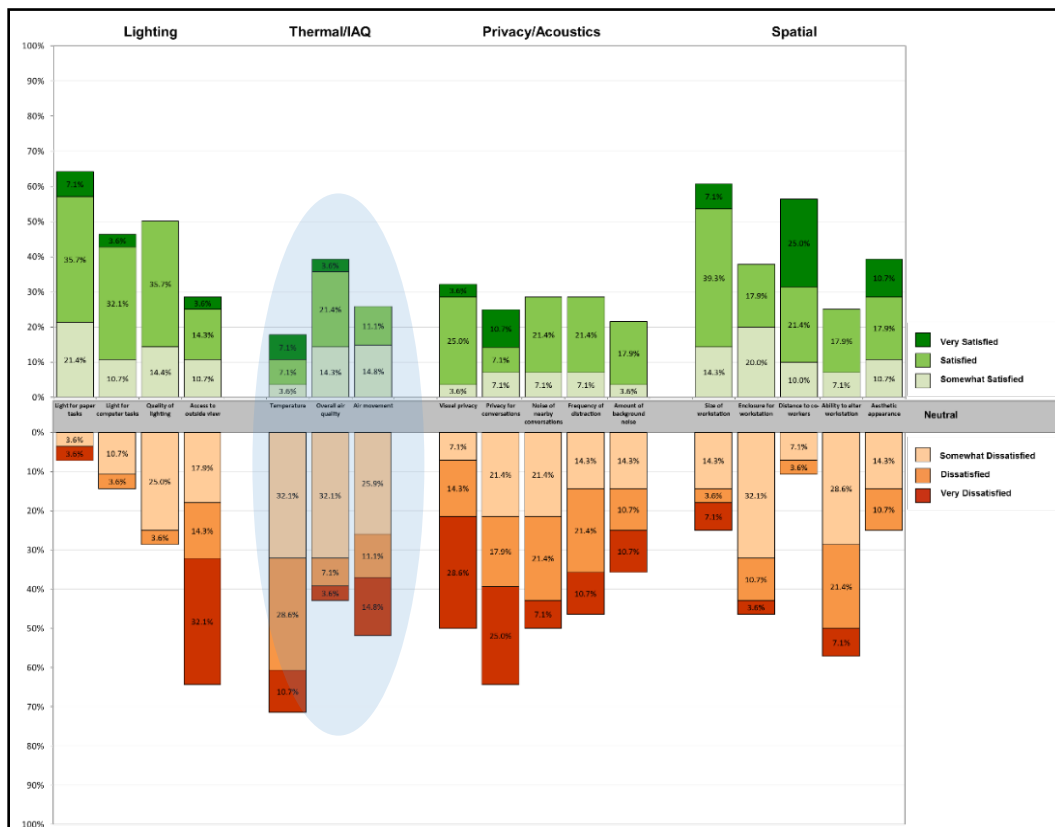

Figure 24. Pre-intervention Survey (n=28)
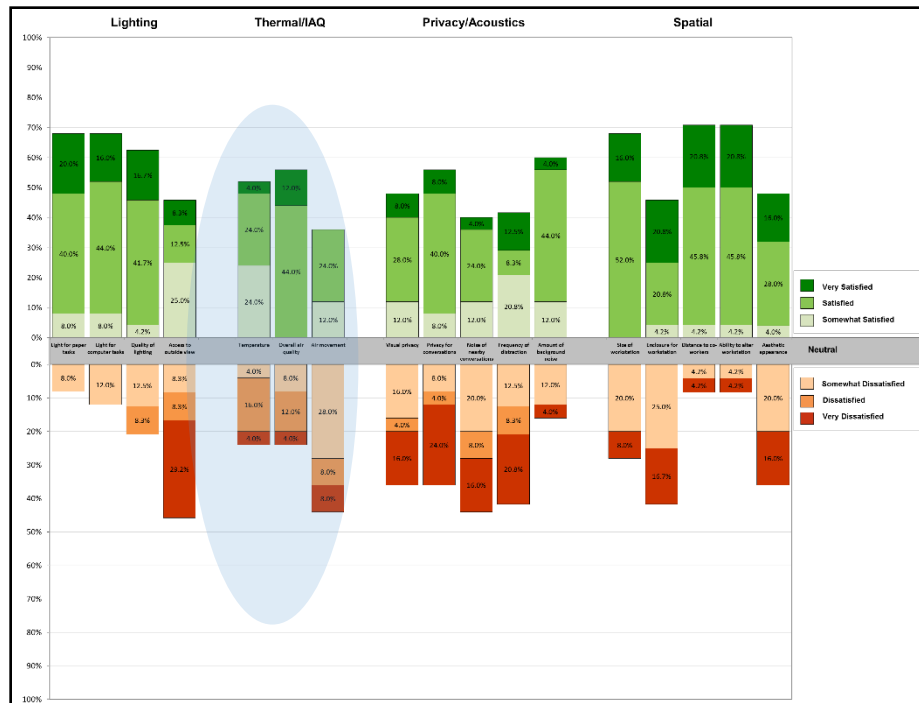
Figure 25. During Intervention Survey (n=25)

During the deployment period, temperature satisfaction rose from 18% to 56%, a great improvement. Dissatisfaction dropped correspondingly from 61% to 24%, with the remaining employees giving neutral responses (Figure 26). The ID-F system helped the facility operator track temperature conditions in every room on the base, and alarms were triggered when rooms with conditions outside the comfort band were detected.
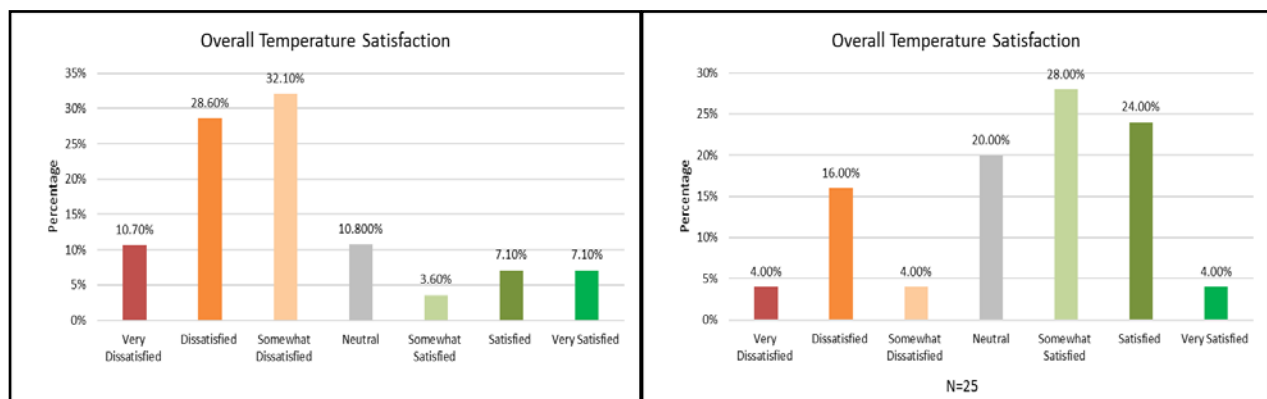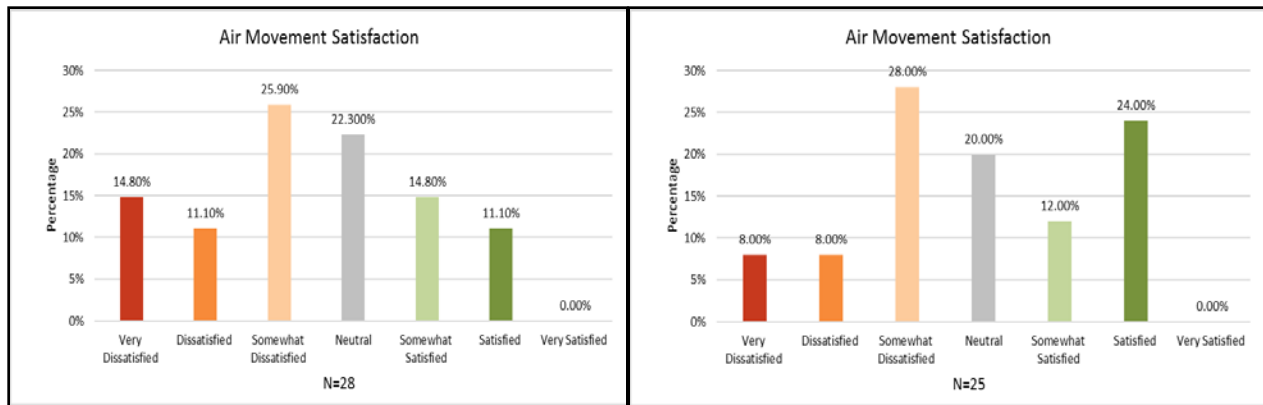

User Satisfaction Survey (n=28)   User Satisfaction Survey (n=25)

Figure 26. Overall User Satisfaction with Temperature on ASHRAE Point Scale

Satisfaction with air movement went from 26% to 36% (Figure 27). The ID-F technology helped the facility operator diagnose the mismatch between the VAVs supply air flow to the current occupancy of the room. The VAVs supply flow rate had been defined during installation for a design occupancy layout that has changed to accommodate different uses over the years.
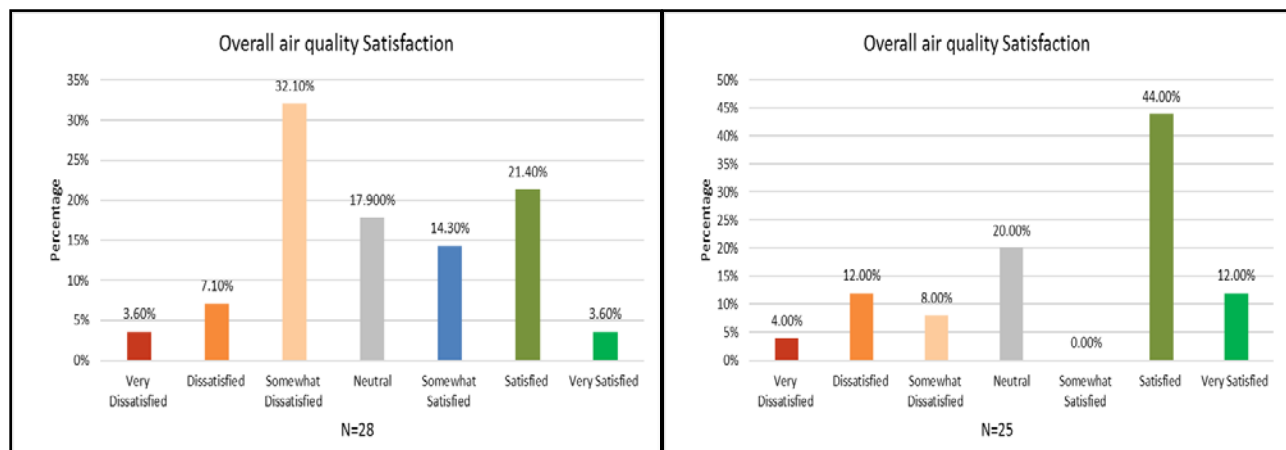
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User Satisfaction Survey (n=28)　　　　　　User Satisfaction Survey (n=25)

Figure 27. Overall User Satisfaction with Air Movement on ASHRAE Point Scale

Overall satisfaction with air quality went from 49% to 56% (Figure 28). This finding correlates to the increase in satisfaction with air movement.

User Satisfaction Survey (n=28)　　　　　　User Satisfaction Survey (n=25)

Figure 28. Overall User Satisfaction with Air Quality on ASHRAE Point Scale

Based on the above results from the occupant surveys it can be concluded that there were measured improvements in occupant satisfaction after the ID-F installation, compared to the baseline. Hence this PO was achieved.

6.8   PO-VIII: PROVIDE ENHANCED FAULT DETECTION

Baseline:

Before implementation of the ID-F technology, the base had no pro-active fault detection and system optimization strategies, and intervention was driven only by complaint-based reactive triggers (direct phone calls from the occupants). A system would go off or its performance would start to drift and the fault would not be detected until it impacted occupants' comfort (temperature out of comfort range, system off, noise…).

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More than 20 faults or incorrect operational sequences were discovered as summarized in Table 15.

Table 15. Fault Diagnostic Summary

| Type	Class	Action Taken	Numbers Detected	Numbers Fixed
AHU/RTUS ON all the time	Operational	Enable calendar Control	7	5
BAS Operator Manual Overrides	Operational	Enable Events in control logic with start and Stop time	10	8
Compressor Short Cycling	Operational	Change control logic PID loop	2	2
Outdoor Lighting on fixed schedule	Operational	Introduce daylight harvesting control	10	10
Incorrect Economizer Control	Operational	Dynamic control of Minimum Outdoor Air intake ratio	3	3
Economizer Damper stuck	Mechanical	N/A, planned in next capital retrofit phase	2	0
Room Temperature out of comfort zone	Operational	Reset Automatic Set-point, Tune VAVs supply air flow	+20	+20

Some examples of faults discovered are presented in the following figures.

A high frequency compressor cycling was discovered on one RTU (Figure 29). Due to a wrong control sequence, the compressor triggered ON/OFF at an alarming rate. The fault was discovered using the building electrical signature collected from the installed sub-meters. A change in the control logic parameters (gain of a PID loop) reduced the cycling of the compressor hence increasing its life expectancy, avoiding potential future replacement capital costs.
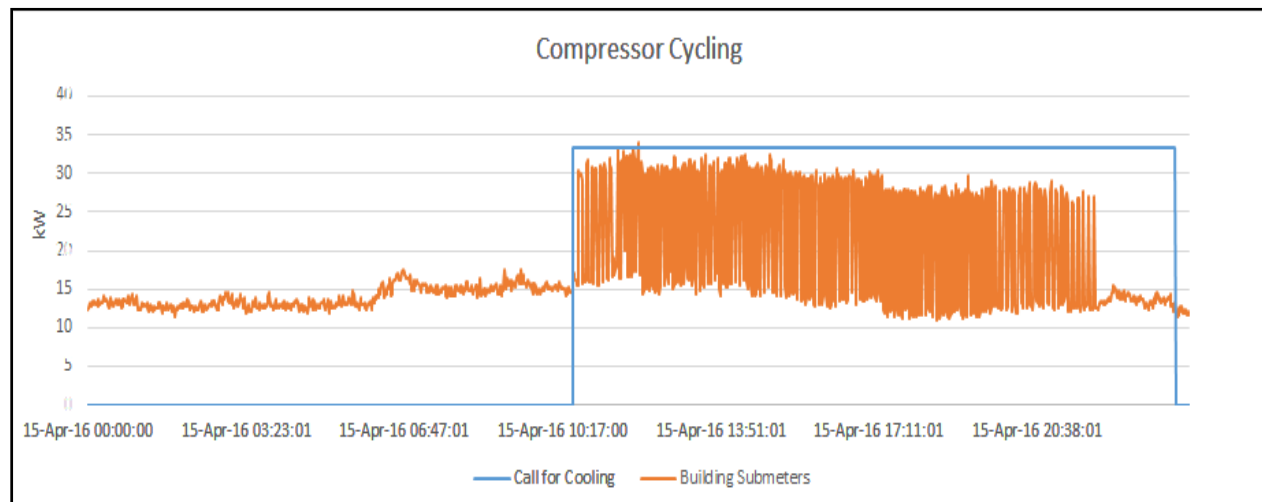
**Figure 29. Compressor Short Cycling**

A large part of the AHUs controls schedules was overridden manually by an Operator who locked them in the ON position following Drill Weekend events. A new control logic following dynamic scheduling and planned events was created. 2 AHUs had to stay ON as they served 24/7 occupied spaces (Figure 30).
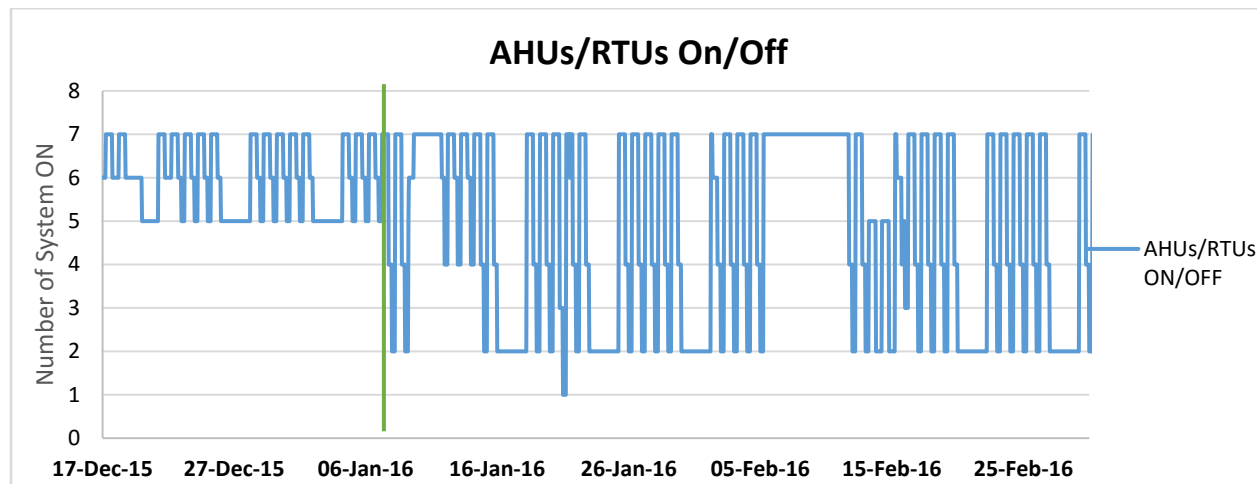
Figure 30. AHUs/RTUs Status

6.9 PO-IX: EASE OF SYSTEM USE BY BUILDING OCCUPANTS

At the end of the ID-O deployment a survey was distributed to the occupants who used the technology to assess the ease of the system and to identify potential improvements. The large majority of occupants' feedback was positive (Figure 31) with more than 65% of the respondents satisfied with the system.
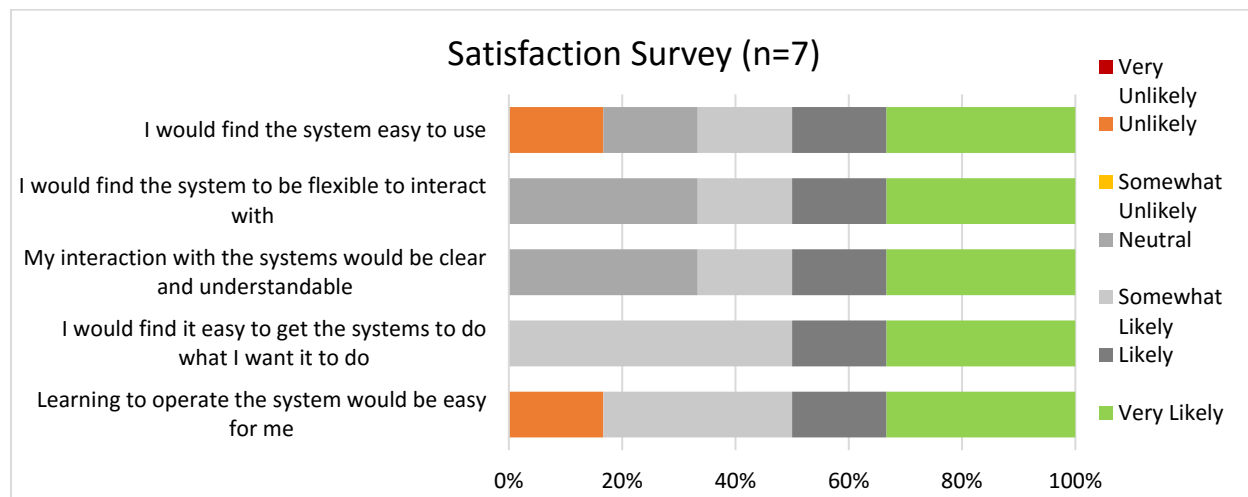
Figure 31. ID-O: Use of System Survey Results

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7.0 COST ASSESSMENT

Building Life-Cycle Cost Program:

The team utilized the Building Life-Cycle Cost Program (BLCC) model to evaluate the cost (cost of owning, operating, and maintaining the energy efficiency investment) and the benefits of the energy conservation investment at the PaANG installation. In compliance with the NIST handbook's guidelines, the team used the actual energy prices of the buildings based on general economic theory. The cost was determined based on actual fees of the demonstration's hard and soft costs which included the cost of the software, license, and equipment, sensors, and engineering fees associated with the ID-O and ID-F demonstration at the PaANG facility.

The methodology to evaluate the cost and energy benefits of the demonstrated technology is applicable for the current project and also general enough so that it can be replicated in other projects. The methodology includes four main steps: 1) install meters and sensors; 2) collect data and measure the energy consumption, occupant satisfaction, and additional existing parameters; 3) install ID-O and ID-F technologies; 4) measure and quantify the benefits of the intervention.

NIST Handbook 135:

The team developed a life cycle cost analysis of the project using rules established in the Life-Cycle Costing Manual for the Federal Energy Management Program. For example, the team used the actual energy price and the measured energy consumption at the building site and calculated the Savings-to-Investment ratio and Adjusted Rate of Return in addition to the ROI.

Life-Cycle Cost Table:

Table 16. Cost Model of ID-F & ID-O Technologies

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	Acquisition cost of computing equipment as required for the installation; additional sensor and meter installation for asset condition monitoring.
Software costs	Licensing costs of ID-F & ID-O software; software customization costs;
Installation/Commissioning costs	1) Engineering effort of building and asset information gathering 2) Engineering effort of Building Automation System Point configuration and trending. 3) Engineering effort of Network configuration and testing 4) RMF certification process
Facility operational costs	Operational Data Collection (prior and post ID-F installation): 1) Trending data retrieval from building automation system (Siemens Apogee); 2) Interval meter data; 3) Utility rate and bills 4) Manual data entry/data collection for network workaround
Maintenance	1) Engineering effort to resolve BAS trending errors 2) Maintenance cost of ID-F
Hardware lifetime	1) Computer replacement cost 2) Optional cost of meter/sensor performance degradation
Operator/occupant training	Estimate of training time for building operator (ID-F) and building occupants (ID-O)
Salvage Value	Estimate of end-of-life value less removal costs

7.1   Cost Model

The cost data presented in Table 17 & Table 18 were used to estimate the life cycle cost for a full-scale deployment. Some costs for this demonstration were for experimental purposes only and will not apply to typical deployments. The cost structure for a typical deployment is discussed in Section 7.1.1 & Section 7.1.2.

Table 17. Cost Model for the ID-O Deployment at PaANG

Cost Item	Cost Estimation
Hardware Costs	$12,000
Software Costs	$2,300
Installation and Commissioning	$1,500
Hardware Lifetime	5 years
Operator Training	$700
Total	**$16,500**

Table 18. Cost Model for the ID-F deployment at PaANG

Cost Item	Cost Estimation
Hardware Costs	$17,000
Software Costs	$30,000
Installation and Commissioning	$4,000
Facility operational costs	$3,000
Hardware Lifetime	15 years
Operator Training	$2,000
Total	$56,000

ID-O costs can be estimated at $85/user - inclusive of hardware, software, training, and commissioning – plus the cost of establishing communications and interface with the BAS infrastructure, which will vary depending on field conditions at a particular installation.

ID-F costs can be estimated at $36,000 – for software, operator training, installation, and commissioning – plus the costs of hardware, site preparation, and facility operation, which will vary depending on the number and size of buildings involved and the BAS infrastructure. In conjunction with installation of the system, the DOD installation may also make a prudent investment to upgrade the metering, sensor, and control capacities of its HVAC and electrical systems.

The direct cost of system deployment at a military installation similar in size to the PaANG test bed would therefore by approximately $75,000. Concurrent upgrades that would enhance the efficacy of the system and be cost effective on their own merits would also be advisable in most circumstances.

7.1.1 ID-O COST DETAILS

The two major types of cost for a full-scale deployment of the ID-O system are hardware and software cost to install and set up the system. The detailed cost data to fully scale deployment of the ID-O technology is broken down for the following categories.

Hardware Costs:

Considering the ID-O deployment for a base like PaANG with 200 employees, each of whom would be given 2 smart wireless plugs, the total hardware cost for the whole base would be $12,000 (Table 17). This include the cost for the wireless plugs and the data collection servers.

Software and Installation/Commissioning costs:

The software cost is calculated to be $2,300. Installation and commissioning can be done at a rate of 8 employees per hour resulting in a total cost of $1,500. The total software and installation cost is estimated to be $3,800.

Operator training:

Simple training is necessary for building occupants to use the ID-O interface to its full capabilities. With group meetings of 15 employees at a time, the total training cost is estimated at $700.

7.1.2 ID-F COST DETAILS

The two major types of costs for a full-scale deployment of the ID-F system are software and installation/setup costs. The detailed cost data to full-scale deployment of the ID-F technology is broken down for the following categories.

Software Costs:

ID-F deployment for a base of around 10 buildings (with BAS similar to PaANG), including software customization: $30,000

Hardware Costs:

Additional server and Ethernet cables that are needed to install and run the ID-F technology and collect data from the BAS system, and third party sensors: $2,000. A budget of $15,000 is allocated for the purchase of electrical sub-meters.

Installation and Commissioning:

Installation and initial commissioning estimated at 1 full time week or 40 man/hours: $4,000

Facility Operation and Maintenance (O&M) Costs:

Operation and maintenance costs for software, hardware, and troubleshooting: $3,000

Operator training:

1 week of training for building system operators to use the ID-F technology to its full capabilities: $2,000.

7.2   COST DRIVERS

The cost drivers that could affect the cost and economics of the ID-O and ID-F technology are site specific and include the following:

- Financial rebate incentives from electric utilities or other sources

- Bases with antiquated building energy management systems (the cost to upgrade the BMS system will increase the initial capital investment)

- Costs for installing a second network (VLAN) to run the ID-O technology for security purposes.

- Cost to address and meet NIST RMF requirements for the ID-O technology

- Cost of sub-metering sensors (Electric, Gas), to reach minimum viable monitoring state.

7.3   COST ANALYSIS AND COMPARISON

The cost-effectiveness for deployment of ID-O and ID-F systems at DOD installations will be different from civilian settings due to cyber-security considerations. DOD cost will be slightly higher, if VLAN communications are required, as was the case for the demonstration. However, if the systems receive authorization under the Risk Management Framework (RFM) for DOD Information Technology, then ID-O software can be installed on the desktops of building occupants, thereby eliminating the need for separate computer interfaces and communications along with their costs. RFM acceptance will also enhance the effectiveness of the system, since separate login will not be required and the system can be accessed easily from a desktop icon. Nevertheless, unlike civilians, military users will not be able to take advantage of wireless technologies to interface with the systems.

The technology provides new and expanding capabilities; it does not replace an existing approach. Consequently, a cost comparison with an existing technology cannot be made.

The ID-O and ID-F systems enhance a BAS capability and can only be used in conjunction with technology that communicates information about the functioning of building systems that consume energy. Since the ID-O and ID-F systems can therefore be considered extension of the BAS, a cost-effectiveness comparison can be made of the combined ID/BAS relative to the BAS without the enhancement. Such cost comparisons would vary for different BAS vendors rather than climatic conditions or energy costs. Viewed as an improvement on existing BAS technologies, the ID-O and ID-F systems provide the cost savings described at Section 6.4

8.0 IMPLEMENTATION ISSUES

The deployment, commissioning and demonstration of the ID-O and ID-F technologies at PaANG helped the team better understand the challenges of implementation at large scale throughout DOD installations. The encountered implementation issues are described in the following paragraphs.

8.1 EXECUTIVE ENGAGEMENT

For many organizations, there are no incentives for facilities managers to reduce energy consumption. The most common roles of the facility manager are to ensure the comfort of the building occupants and the smooth operation and maintenance of building equipment. This leads to reactive maintenance practices where systems commissioning is only triggered following occupants' complaints or system failures. The PaANG base is no exception.

As a result of providing real-time analytics, the ID-F technology now enables predictive maintenance and building operation and helps the facility manager optimize the base's operation and, potentially, save energy. This technology, coupled with performance incentives from the executive team, can help further reduce energy consumption.

Overall energy conservation messaging from the executive team (e.g. base commander) is also needed to help engage the building occupants towards energy conservation.

8.2 USERS ENGAGEMENT

The ID-O interface/dashboard enables the building occupant to view the plug load energy consumption and control the office equipment connected to smart meters. However, the dashboard was installed only on separate laptops. Use of separate laptops, connected to the base's VLAN, was necessary to reduce the potential for a security breach into the military's SIPRnet and NIPRnet. The separation/decoupling of the day-to-day desktop unit being used by personnel from the laptop with the ID-O interface limits the participants' interaction with the ID-O dashboard. The plug-load energy savings and dashboard interaction could potentially be higher if the ID-O interface were integrated to the main day-to-day desktop unit.

8.3 SECURITY CONCERNS

The proximity of Building 107, one of our initial sites of the ID-O technology, to the base's communication center precludes its deployment, due to security concerns. The base, as with other military installation, has a protocol of not selecting wireless technology, in order to reduce the risk of a security breach. The ID-O technology relies on ZigBee mesh network, which has a very short range, was tested to ensure that the network was limited to Building 205, the deployment site.

8.4 ISSUE WITH EQUIPMENT

One of the earlier findings from the project was the existence of electrical smart-meters that were never connected to any data collection platform. The first step was to bring the meters online and

collect the data for trending and analytics. In addition new sub-meters were installed at locations with potential high-energy usage. However, the new smart meters had to be hard-wired due to restriction on the wi-fi network, which significantly increased the installation cost and deployment time.

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APPENDIX A   POINTS OF CONTACT

Point of Contact Name	Organization	Phone Email	Role in Project
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Elizabeth Fox	Carnegie Mellon	(412) 268-8178 lizfox@cmu.edu	Business Contact
Paul Sedlock	SBT	(412) 527-7404 paul.sedlock@siemens.com	Key Contributor (Instrumentation)
Mark Benninger	OSIsoft	(703) 371-3231 cdiffie@osisoft.com	Key Contributor (Data Collection)
Enes Hosgor	EEME	(512) 706-5054 enes@energyefficiency.me	Key Contributor (Data Analytics)
Erica Cochran	EEME	(646) 373-9009 erica@energyefficiency.me	Key Contributor (Data Analytics)
Peter Winslow	Evolve	(914) 227-3795 pjwinslow@gmail.com	Key Contributor (Reporting)
Joseph Sullivan	PaANG	(412) 776-7621 joseph.sullivan.1@ang.af.mil	Site Support

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APPENDIX B ON-SITE OCCUPANT SATISFACTION SURVEY

CMU's On-Site User Satisfaction Questionnaire (based on NRC COPE [i])

What building are you in (address or title)? _____

What floor? _____

How long have you worked here? _____

In a typical work week how many hours do you spend here? _____

How do you feel about?

		Dissatisfied			Neutral	Satisfied		
		Extremely	Moderately	Slightly		Slightly	Moderately	Extremely
1	Light on the desk for paper-based tasks (reading & writing)	-3	-2	-1	0	1	2	3
2	Overall air quality in your work area	-3	-2	-1	0	1	2	3
2a	Odors in your work area	-3	-2	-1	0	1	2	3
3	Temperature in your work area	-3	-2	-1	0	1	2	3

	Temperature in your work area during:	Very Cold			Neutral		Very Hot	
3a	Winter	-3	-2	-1	0	1	2	3
3b	Summer	-3	-2	-1	0	1	2	3
3c	Swing Seasons	-3	-2	-1	0	1	2	3

		Very Dissatisfied			Neutral		Very Satisfied	
4	Aesthetic appearance of your work area	-3	-2	-1	0	1	2	3
4a	Cleanliness of your work area	-3	-2	-1	0	1	2	3
5	Level of acoustic privacy for conversations in your work area	-3	-2	-1	0	1	2	3
6	Level of visual privacy within your work area	-3	-2	-1	0	1	2	3
7	Amount of noise from other people's conversations while you are at your workstation	-3	-2	-1	0	1	2	3
8	Size of your personal work area to accommodate your work, materials and visitors	-3	-2	-1	0	1	2	3
9	Amount of background noise from mechanical or office equipment you hear at your workstation	-3	-2	-1	0	1	2	3
10	Light for computer work	-3	-2	-1	0	1	2	3

	How often do you experience glare:	Always	Morning	Noon	Late Afternoon	Night	Never
11	On your computer screen	☐	☐	☐	☐	☐	☐
12	From Electric Lighting Fixtures	☐	☐	☐	☐	☐	☐
13	From Daylight	☐	☐	☐	☐	☐	☐

		Very Dissatisfied			Neutral		Very Satisfied	
14	Air movement in your work area	-3	-2	-1	0	1	2	3

	If dissatisfied with the air movement, how do you feel during:	Stuffy	Drafty	Both	N/A
14a	Winter	☐	☐	☐	☐
14b	Summer	☐	☐	☐	☐
14c	Swing Seasons	☐	☐	☐	☐

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APPENDIX C   ID-O SOFTWARE USABILITY SURVEY

1. Building Number?

2. How would you describe the work you do?

Executive / Managerial	☐
Professional / Technical	☐
Clerical / Support	☐
Other (please specify)	

3. In a typical week, how many hours do you typically spend at your desk?

	Hours a week
Doing computer work	
Doing paper work	
On the telephone	
Total	

4. In a typical week, how many hours do you spend working away from your desk?

Hours away from your desk (hours/week):	

5. How often do you turn off or unplug your:

	Never	*Rarely*	*Sometimes*	*Often*	*Always*	*N/A*
Computer when not in use on nights and weekends?	☐	☐	☐	☐	☐	☐
Computer monitor when not in use on nights and weekends?	☐	☐	☐	☐	☐	☐
Task light (lamp, under cabinet light) when not in use?	☐	☐	☐	☐	☐	☐
Office phone on nights and weekends?	☐	☐	☐	☐	☐	☐

6. Have you:

	Yes	*No*	*Do not know*	*N/A*
Adjusted power settings (e.g., to power saver mode) for the computer you are using at PaANG?	☐	☐	☐	☐
Adjusted brightness settings for your computer monitor at PaANG?	☐	☐	☐	☐
Discussed energy usage/saving in your work group?	☐	☐	☐	☐

7. How often does your organization:

	Never	Rarely	Sometimes	Often	Always	Do not know
Provide workers with very energy efficient products (e.g., computers, displays, lights)?	☐	☐	☐	☐	☐	☐
Encourage workers to reduce energy use in the office?	☐	☐	☐	☐	☐	☐

8. Put in order the actions you think will have the greatest impact on energy savings: (1st: highest - 7th: lowest)

	Order of Impact
Turn the computer off when not in use (e.g., nights, weekends)?	
Turn the computer monitor off when not in use (e.g., nights, weekends)?	
Turn the task light (lamp, under cabinet light) off when not in use (e.g., nights, weekends)?	
Turn the phone off or unplug it when not in use (e.g., nights, weekends)?	
Adjust computer power settings (e.g., to power saver mode)?	
Adjust computer monitor's brightness settings?	
Buy energy star office equipment such as: computers, printers, lights, and so forth?	

9. What currently drives your workgroup to save energy in the office?

	Not at all	Only a little	Somewhat	A lot	Completely	N/A
Office energy saving goals and policies	☐	☐	☐	☐	☐	☐
Workgroup energy saving goals and policies	☐	☐	☐	☐	☐	☐
Supervisor's attitude on saving energy	☐	☐	☐	☐	☐	☐
Co-workers' attitudes on saving energy	☐	☐	☐	☐	☐	☐
Personal commitment to saving energy	☐	☐	☐	☐	☐	☐
Knowing how much energy we use	☐	☐	☐	☐	☐	☐
Our desire to learn new ways to save energy	☐	☐	☐	☐	☐	☐
Saving energy is an integral part of our workgroup	☐	☐	☐	☐	☐	☐

Perceived Ease of Use

	1 (Unlikely)	2	3	4	5	6	7 (Likely)	N/A
Learning to operate the system would be easy for me	☐	☐	☐	☐	☐	☐	☐	☐
I would find it easy to get the systems to do what I want them to do	☐	☐	☐	☐	☐	☐	☐	☐
My interaction with the systems would be clear and understandable	☐	☐	☐	☐	☐	☐	☐	☐
I would find the system to be flexible to interact with	☐	☐	☐	☐	☐	☐	☐	☐
I would find the system easy to use	☐	☐	☐	☐	☐	☐	☐	☐

Does the use of the tool increase your overall awareness of energy consumption within a building?

Yes	No	N/A
☐	☐	☐

Are you more aware of individual appliance's energy consumption after using the Dashboard?

1 (Very Unaware)	2	3	4	5	6	7 (Very Aware)	N/A
☐	☐	☐	☐	☐	☐	☐	☐

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APPENDIX D   ID-F SOFTWARE USABILITY SURVEY

Occupant Complaint Handling

1. How much of your department's time is typically spent responding to occupant complaints or requests every month?

2. What percentage of complaints or requests would you describe as purely subjective?

3. Have you had success with any of the following steps to minimize the time spent handling subjective or frivolous requests?

   - Automated work order systems
     - *Very Successful – Somewhat Successful – Not Successful – Not Tried*
     -
   - Education of and Communication with Occupants
     - *Very Successful – Somewhat Successful – Not Successful – Not Tried*
     -
   - Training of Facility Staff
     - *Very Successful – Somewhat Successful – Not Successful – Not Tried*
     -

Perceived Usefulness

4. Using the system in my job would enable me to accomplish tasks more quickly
   (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

5. Using the system would improve my job performance
   (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

6. Using the system in my job would increase my productivity
   (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

7. Using the system would enhance my effectiveness on the job
   (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

8. Using the system would make it easier to do my job
   (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

9. I would find the system useful in my job
   (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

Perceived Ease of Use

10. Learning to operate the system would be easy for me
    (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

11. I would find it easy to get the systems to do what I want them to do
    (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

12. My interaction with the systems would be clear and understandable
    (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

13. I would find the system to be flexible to interact with
    (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

14. It would be easy for me to become skillful at using the system
    (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

15. I would find the system easy to use
    (Unlikely) – 1 – 2 – 3 – 4 – 5 – 6 – 7 (Likely) – NA

APPENDIX E   SMART PLUG METERS

The ID-O technology can be used with any plug load wireless hardware technologies that provide a front-end API for control and data collection.

For this demonstration project, the team used the Plugwise® wireless meter technology. The wireless devices named "Circle" are installed between the electrical outlet and the appliance electrical cord. The meters create a Zigbee peer-to-peer mesh network to communicate back to the data collection server. Up to 65 circles can be connected to one server.
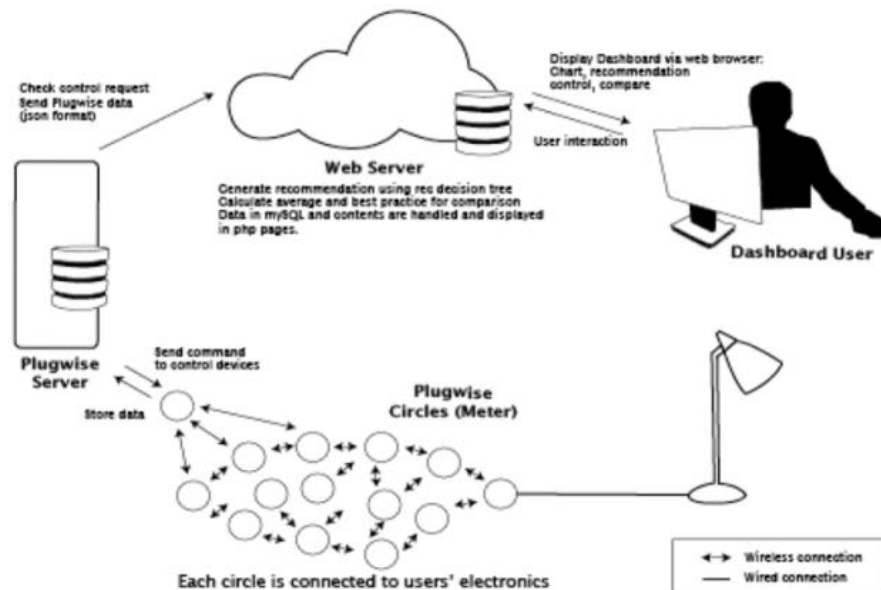

Figure 32: Plugwise Wireless Sensor

Figure 33: System Architecture